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MERTON BENWAY WAITE

1865–1945

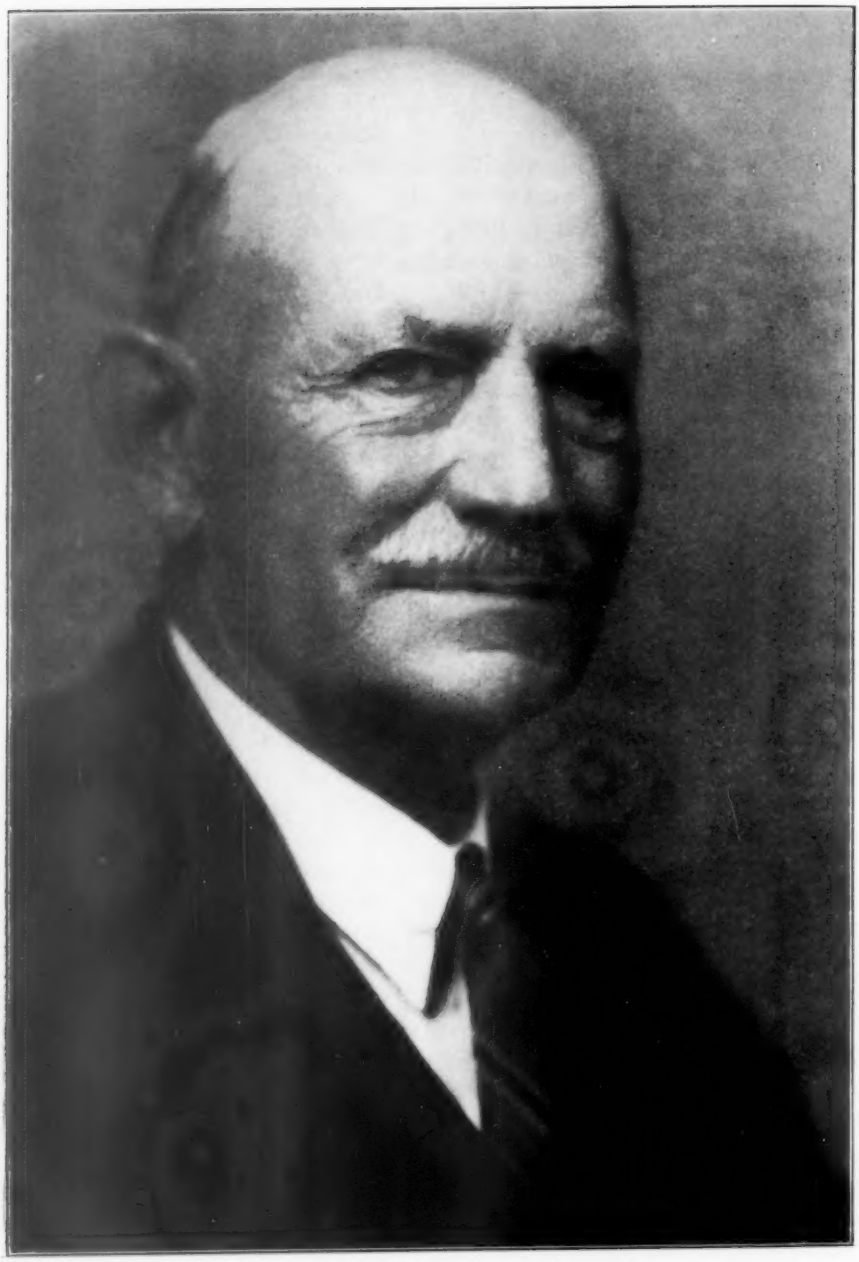
JOHN W. ROBERTS

The death of Merton Benway Waite on June 5, 1945, marked the passing of another of those early workers who, by the brilliance of their discoveries, helped to create the Bureau of Plant Industry and to establish public confidence in the usefulness of plant pathology.

Born January 23, 1865, on a farm near Oregon, Illinois, in the botanically interesting Rock River country, he developed an interest in plants while still in high school, an interest that was paramount throughout the rest of his life.

When he entered the University of Illinois, from which he was graduated in 1887, his parents hoped he would take a civil engineering course, but his love for plants and the influence of Dr. T. J. Burrill, Professor of Botany, soon prevailed. After graduation he became an assistant to Burrill, but Galloway, in his hunt for promising young men for his Section of Vegetable Pathology, soon chose him and from then, November 1, 1888, until his retirement in 1935, Waite was a member of that organization and its successor, the Bureau of Plant Industry. From 1901, he was in charge of the Office, later Division, of Fruit Disease Investigations. He brought to the pathologists of the Department the technic of isolating and growing bacteria and fungi in pure culture on artificial media, which he had learned under Burrill, and taught it with characteristic enthusiasm not only to his colleagues in the Department but to many visiting investigators from colleges and universities as well. One of his greatest pleasures was in teaching others these methods and his own improvements.

Waite will always be known for his work on blight of pomaceous fruits. He first demonstrated the dissemination of the pathogen by insects, an epoch-making discovery in the field of disease control. As an outgrowth of this work with pear blight and primarily because of his keen powers of observation, he also discovered that most varieties of pear required cross-pollination with other varieties to set an adequate crop of fruit. His proof of this fact is a model of exact experimental work that soon convinced the skeptics. This discovery, soon extended to other fruits, has profoundly affected orchard planting throughout the world. Fifty years ago at the frantic request of grower organizations Waite organized and led a campaign of pear-blight eradication, using methods largely originated by himself, that saved the pear industry of the Pacific Coast States from probable destruction. The methods used and taught by him are used today with only minor changes. A few years later and with the exercise of great patience he convinced the hardheaded apple growers of the Shenandoah Valley that the destruction of cedar trees would prevent defoliation by cedar rust, thus laying the foundation for the present cedar-rust law. His knowledge of fruit



MERTON BENWAY WAITE
1865–1945

diseases was probably beyond that of any investigator of his day, but in his later years he published little. To his visitors and colleagues, however, he always gave bountifully of his knowledge.

Waite helped organize and was a member of the Federal Insecticide and Fungicide Board, which administered the Insecticide law of 1910, until 1924, when he relinquished membership in this Board to become a member of the Federal Horticultural Board, which established and enforced the Federal quarantine regulations until its functions were taken over by another agency. On both these boards his services were distinguished, not only by his knowledge of plants, plant diseases, and horticultural practices, but by his scientific attitude and fairness.

In 1919 he was given the honorary degree of Doctor of Agriculture by the University of Maryland. He was a charter member of The American Phytopathological Society, Fellow of the American Association for the Advancement of Science, and a member of the Washington Academy of Science and other scientific societies. He helped to found and was twice president of the Botanical Society of Washington, in which he took a great interest up to the very day he was stricken. He seldom missed a meeting and usually furnished the flowers for the annual dinner.

Possessed of a pleasant disposition and always smiling, Waite was popular with his associates and always willing to be helpful to them. His zest for living, which continued to the day of his final sickness, makes it hard for us to realize that he is gone. His restless energy gave an impression of indestructibility that made death seem impossible.

In 1944, at the age of 79, he revisited his former collecting grounds in Illinois with the enthusiasm of youth and returned to Washington with an interesting account of the botanical changes and the finding of certain rare plants just where he expected them to be.

Those of us who were his associates for many years will miss him, not only because of his scientific attainments but because of his enthusiasm, his kindliness, and an optimistic view of life that lasted to the very end.

He is survived by his wife, Elizabeth Hurdle Waite, and two sons, Merton and Malden, both of whom are captains in the armed forces.

BOTANICAL WRITINGS OF M. B. WAITE

(Compiled by J. A. Stevenson and Edith K. Cash)

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THE LIFE HISTORY OF THE GOLDEN NEMATODE OF POTATOES, HETERODERA ROSTOCHIENSIS WOLLENWEBER, UNDER LONG ISLAND, NEW YORK, CONDITIONS[1]

B. G. Chitwood and Edna M. Buhrer

(Accepted for publication July 24, 1945)

INTRODUCTION

At the present time there are four nematodes known to cause damage to potatoes in the United States: the root-knot nematode (*Heterodera marioni* (Cornu) Goodey) and Scribner's meadow nematode (*Pratylenchus scribneri* Steiner in Sherbakoff & Stanley), both prevalent throughout the potato acreages of the country; the potato-rot nematode (*Ditylenchus destructor* Thorne), occurring in a single area of Idaho; and the golden nematode of potatoes (*Heterodera rostochiensis* Wollenweber), occurring in a single area of Long Island, N. Y. The first two are prevalent and commonly cause considerable loss in crop on Long Island. *H. rostochiensis* causes considerably more damage in the area of its occurrence but is of minor importance when national crop losses are considered. The potential damage which could be expected from it, were it general, is our primary consideration, for it causes major losses throughout the entire northern potato-growing regions of Europe and the British Isles. Leiper[2] states concerning this disease: "Once its nature and importance had been realized, reports of its occurrence multiplied so rapidly that, by the early post-war period, practically all the potato-growing districts of Britain were known to have foci of infection. Since then infection has progressively increased in intensity so that to-day much of the potato land is ceasing to be economically productive, and consequently its once high market value has markedly depreciated."

While the golden nematode of potatoes was not discovered in the United States until 1941, our observations on the rate of its multiplication and spread indicate that it was introduced into Long Island around 1930. By 1934 there were a few isolated spots showing poor potato growth and by 1938 these spots had multiplied and requests for soil analysis had been made by the growers. In 1941 the potato growth was poor throughout the field on which these spots had been observed, and it was at that time that the causative organism was identified. In 1942 a cooperative survey showed infestation in 14 fields totaling 434 acres, in 1943 as many as 23 fields totaling 840 acres, and in 1944, 26 fields totaling 918 acres. In the meantime the State

[1] Investigations on this potato pest are carried on by the Division of Nematology, Bureau of Plant Industry, Soils and Agricultural Engineering, and the Division of Domestic Plant Quarantines, Bureau of Entomology and Plant Quarantine, both of the Agricultural Research Administration, U. S. Department of Agriculture; the Agricultural Experiment Station at Cornell University; and the New York State Department of Agriculture.

[2] Leiper, R. T. The potato eelworm problem of to-day. Jour. Roy. Agr. Soc. England 100(3): 63–73. 1940.

of New York has enacted certain regulations to prevent local and national dispersal of the pest.

During the summer of 1944 we participated in a survey of the potato growing areas of the northeastern United States, which was conducted cooperatively with the Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture. In this survey 1480 farms, totaling 48,156 acres, were inspected for the presence of *Heterodera rostochiensis*. Although the survey represented a general sampling of the potato lands of 19 States, not a single instance of golden nematode was observed. While our survey could embrace only the examination of representative samples and, while negative findings are never conclusive, it can be stated that the odds are 99 : 1 that less than 4 farms in 1,000 and less than 2 acres in 10,000 are infested in the areas surveyed. It would appear that *H. rostochiensis* is wholly or chiefly confined to a single area of Long Island at the present time. From the national standpoint this area of infestation is important as a source of new infestations and as a threat to the potato industry of the country.

LIFE HISTORY OF THE NEMATODE

Eggs and larvae of *Heterodera rostochiensis* overwinter in the body of the dead female which has been transformed into a brown, thick-walled, protective cyst. In spring the eggs hatch and larvae emigrate from the cysts to attack potato roots. This activity is at least partially dependent upon temperature, and will be discussed later. The invading larvae penetrate any part of the root system or tubers, taking up a position with the head near the vascular system. The posterior part of the body may completely or only partially enter the root. Figure 1 shows the various stages of nematode development. The first and second molts are passed through rapidly (probably within 5 to 7 days after invasion) and there is little change in gross form during this period, though we believe the sexes can be distinguished through the thickening of the rectum in the male. Contrary to the development in *H. marioni* as given by Christie and Cobb,[3] no molt appears to take place in the egg. We believe two molts take place in the larviform or slender period, evidence being a difference in the form of the cast-off portion of the stylet (Fig. 1, D1 ♂ & C ♀) and the coarser striation of the first-stage cuticle.

During the third stage (approximately 10 days after invasion) the posterior part of the body enlarges in both sexes, and may at this time break through the root epidermis if the specimen is lodged in a small root or near a root surface. During the fourth stage (also about 10 days) the posterior part of the body of the female continues to enlarge, very rapidly becoming spheroid, and many more specimens break through the root surface. The fourth stage male elongates, reassuming the vermiform shape, coiled within the third stage cuticle. During the latter part of the fourth stage the thick

[3] Christie, J. R., and Grace Sherman Cobb. Notes on the life history of the root-knot nematode, *Heterodera marioni*. Proc. Helminthol. Soc. Washington **8**: 23–26. 1941.

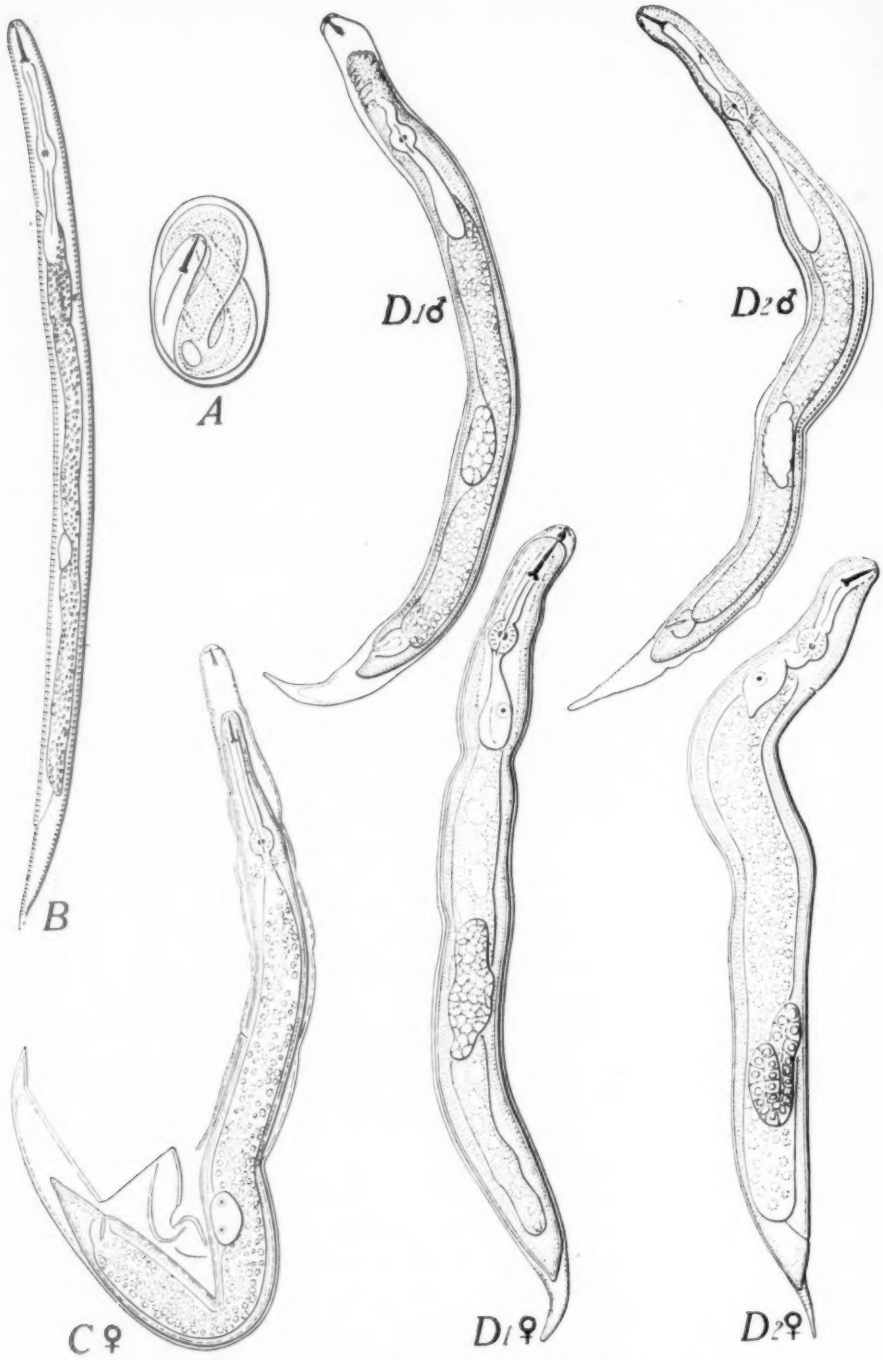

FIG. 1. Stages in the life history of *Heterodera rostochiensis*. Lettering and numbering arranged to identify corresponding stages in both sexes. All about 300×.

A—Egg containing larva, sex undeterminable.

B—Larva broken out of egg (1st stage), sex undeterminable.

C♀—Larva (? female) in 1st molt.

D1♂—Larva (? male) in early phase of (?) 2nd molt.

D1♀—Larva (? female) in early phase of 2nd molt.

D2♂—Same, in final part of (?) 2nd molt.

D2♀—Larva (female) in final phase of 2nd molt.

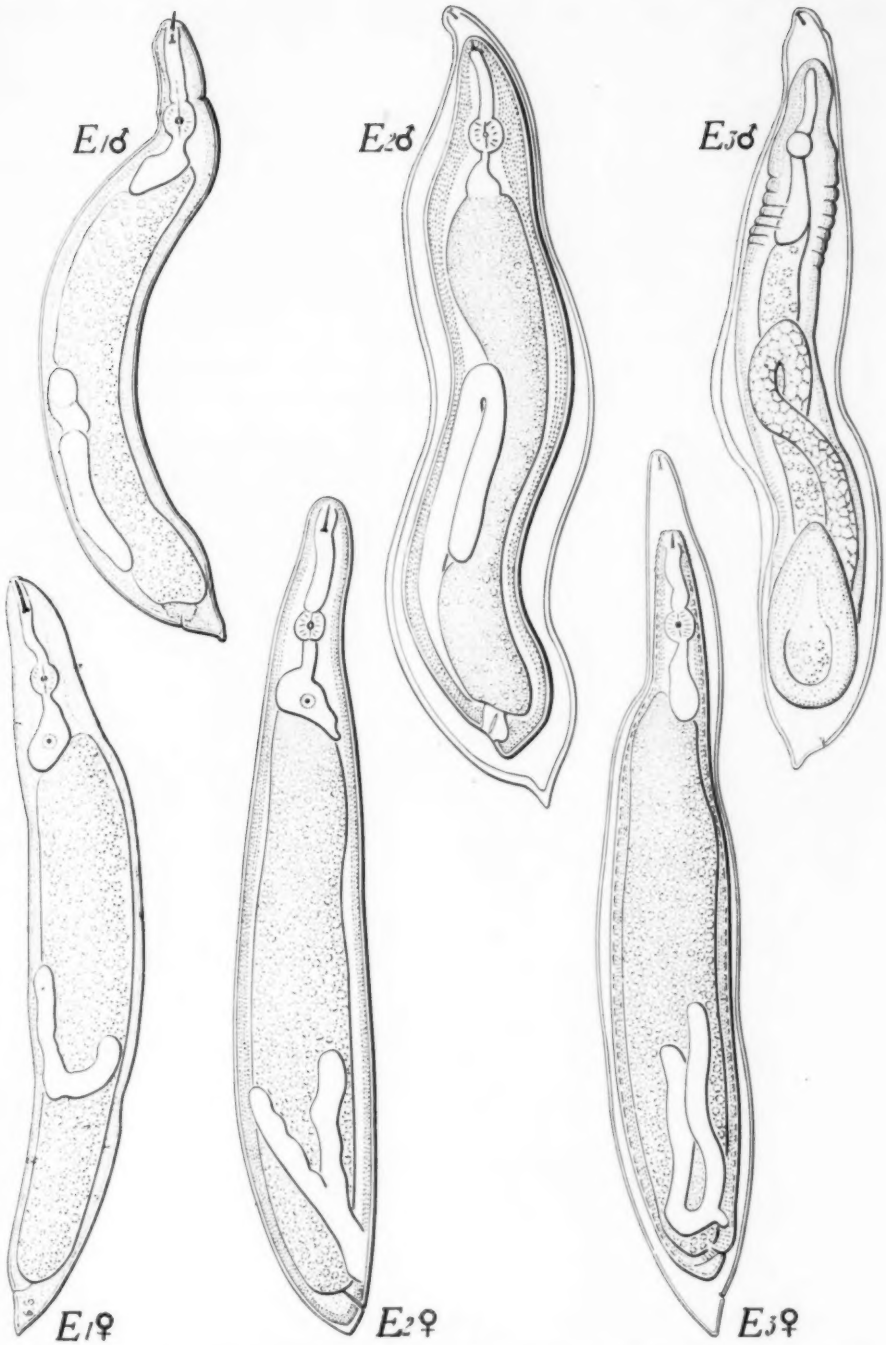

FIG. 2. Stages in the life history of *Heterodera rostochiensis*, continued from figure 1. Lettering and numbering arranged to identify corresponding stages in both sexes. All about 300 ×.

E1 ♂ — Larva, 3rd stage male.
E2 ♂ — Larva, molting 3rd stage male.
E3 ♂ — Larva, coiling early 4th stage male (in 3rd cuticle).
E1 ♀ — Larva, early 3rd stage female.
E2 ♀ — Larva, late 3rd stage female.
E3 ♀ — Larva, molting 3rd stage female.

FIG. 3. Stages in the life history of *Heterodera rostochiensis*, continued from figure 2. Lettering and numbering arranged to identify corresponding stages in both sexes. All about 300 ×.

F ♂ — Larva, 4th stage male, beginning 4th molt.

G1 ♂ — Adult male ensheathed in 3rd and 4th cuticles.

G2 ♂ — Adult male after exsheathing.

F ♀ — Larva, 4th stage female.

G ♀ — Adult female after 4th molt. (Considerable growth is accomplished after this stage.)

refractive cuticle of the adult female begins to form. Prior to its formation females are practically invisible to the naked eye because of their transparency and protoplasmic gray color. With the advent of the adult cuticle females turn opaque, waxy, or pearly-white, and thus become macroscopically visible. This transformation gives the impression of sudden, multiple emergence from the root, although actually specimens of all stages can be found at this time, if examined microscopically, the posterior portions of their bodies projecting outside the root. Specimens that have completely entered the root may subsequently break through its surface in the third, fourth, or adult stage. Males may either cast or retain the cuticle of the third stage before proceeding to the final or fourth molt.

FIG. 4. Potato roots infected with *Heterodera rostochiensis*. Left: Adult female nematodes shown as spherical bodies clustered on root. ×8. Center: Isolated piece of root showing one female pressing through root surface and several craters where others have fallen out. ×4.5. Right: 2 isolated pieces of root; females glisten immediately after being removed from soil; 7 specimens can be found on extreme right-hand root. ×4.5.

During the 16 days following the final molt the female turns from white to yellow and eggs are produced (Fig. 4). As the season progresses, the females become golden, are finally transformed into a brown cyst containing eggs capable of overwintering, and the cycle is complete. In some instances hatching larvae were observed within yellow females as early as June 16; we have been unable to verify this point, however, from preserved material of that date, although we have seen fully developed larvae present in the eggs. We are therefore uncertain whether such eggs hatch normally, thereby permitting larvae of a second generation to invade potato roots during the same season. It is known that invasion of roots (and tubers) continues throughout the growing season, but this could be the action of larvae from

old cysts. The eggs and larvae from a cyst do not all become active at the same time, but hatch and emigrate over a period of years.

To summarize, then, it may be said that the nematodes pass through the four molts within a period of 23 to 33 days and begin to produce eggs containing larvae within 16 days thereafter. The entire period from embryonated eggs to embryonated eggs is not less than 38 and does not exceed 48 days. During this period, in the experiments of 1944, the weekly mean soil temperatures were 59°, 58°, 63°, 63°, 66°, and 69° F., chronologically.

RELATION TO POTATO HOST

An effort was made to establish a correlation between hatching of eggs plus emigration of larvae, and soil temperatures. Table 1 shows counts of eggs and larvae per cyst on April 25, May 5, and May 26, 1944. There was

TABLE 1.—*Contents of cysts of Heterodera rostochiensis in relation to date, in 1944. (Means of 10 cysts from 10 samples of soil per date)*

Stage of nematode	Number found on		
	April 25	May 5	May 26
Eggs	57	43	43
Larvae	15	15	10
Both eggs and larvae	72	58	53

a definite reduction in the number of eggs in cysts between April 25 and May 5, indicating that hatching was taking place. The number of larvae remained constant between these dates, which we interpret to mean that emigration of larvae from the cysts kept pace with hatching. There is no evidence of hatching between May 5 and May 26, but emigration of larvae continued. Larvae were first seen in potato roots on May 9, in the observations of 1944. Before that date weekly mean soil temperatures had been 49° to 51° F. (between April 7 and 28), then suddenly rose to 59° F. for the week of April 29–May 5. Thereafter they were 58° F. or higher. Evidence in previous years has indicated nematode dormancy at weekly mean temperatures up to 54° F., but there was no such period in 1944.

The life history of the nematode is inalterably linked with that of the potato plant. A study was therefore made of the growth rate of the latter, with special reference to the influence of soil temperature. Potatoes of each of three varieties were planted in five randomized plots on clean and on infested soil, and were allowed to root. After one week, a plant of each variety was taken at random from each of the five clean and five infested plots, and its root system weighed. This process was repeated weekly for the succeeding six weeks. Table 2 gives the total weights of each group of five plants at the various dates, together with the weekly mean soil temperatures of those dates. It will be seen that the variety Irish Cobbler is capable of some root growth at 49° F., while Green Mountain and Houma are not. Both of

TABLE 2.—*Weights in grams of root systems of 3 potato varieties*

Date (1944)	Variety						Mean soil temperature (degrees F.)
	Irish Cobbler		Green Mountain		Houma		
	Inf. soil	Clean soil	Inf. soil	Clean soil	Inf. soil	Clean soil	
Apr. 25	0.0[a]	0.0	0.0	0.0	0.0	0.0	49
May 1	0.6	0.1	0.0	0.0	0.0	0.0	49
8	2.5	4.6	0.1	0.2	0.0	0.4	59
12	8.1	21.1	0.9	7.0	1.6	14.2	58
22	23.5	23.4	10.1	18.0	12.6	17.2	63
29	34.0	42.1	19.2	17.6	33.5	22.0	63
June 5	33.0	41.9	18.0	24.9	45.0	40.3	66

[a] Each weight is the total of 5 root systems, 1 plant from each replicate.

the latter are capable of root growth at 58° F.[4] In comparing the growth in clean and infested soils, unfortunately we cannot attribute the differences solely to the effect of *Heterodera rostochiensis* since other nematode pathogens (*H. marioni* and *Pratylenchus scribneri*) were also present. It can be said, however, that root growth of all varieties was delayed in the infested soil. The difference between root growth in clean versus infested soil was greatest about May 15, after which there was a root stimulation or proliferation in the case of plants growing in infested soil, that tended to reduce this difference.

Observations from previous years had already indicated that *Heterodera rostochiensis* caused minor damage to Irish Cobbler and major damage to Green Mountain and Houma. Injury shows in the form of delayed emergence and stunting of the plants, and reduced yields of the crop. We believe that the relation of spring soil temperatures to nematode activity and to potato growth accounts for the differences in crop losses due to nematodes in the several varieties of potatoes. These relationships are shown in table 3.

TABLE 3.—*Effect of soil temperature on growth of potato roots and invasion by Heterodera rostochiensis*

Mean soil temperature (degrees F.)	Invasion of nematodes	Growth of potato roots[a]	
		Irish Cobbler	Green Mountain
45	–	(+)	– –
49	–	+	– –
53	(–)	+	?
54	(–)	+	(+)
57	(+)	++	+
58	(+)	++	+
59	+	++	+
62	++	++	++

[a] (+) or (–) Activity or inactivity (of nematodes or root growth, as the case may be), as based on circumstantial evidence.
+ or – Activity or inactivity, as based on direct observations of specimens.
++ or – – Pronounced activity or inactivity, as based on direct observations of specimens.

[4] Evidence from previous seasons indicates minor root growth of Irish Cobbler at 45° F. and of Green Mountain at 54° F.

TABLE 4.—*Yields and production costs of 2 potato varieties in clean and in Heterodera rostochiensis–infested soils*

Variety and year	Yield in cwt./acre			Cost of production (in dollars)/cwt.		
	Clean soil	Mod. inf. soil	Heavily inf. soil	Clean soil	Mod. inf. soil	Heavily inf. soil
Irish Cobbler:						
1941	172	.....	144	0.85	.....	1.05
1942	192	.....	133	0.80	.....	1.15
1943	138	137	70	1.10	1.10	2.15
1944	135	84	82	1.10	1.80	1.85
Summary	135–192	84–137	70–144	0.80–1.10	1.10–1.80	1.05–2.15
Green Mountain:						
1943	148	103	58	1.00	1.45	2.60
1944	110	.....	32	1.35	.....	4.70
Summary	110–148	103	32–58	1.00–1.35	1.45	2.60–4.70

It would seem that Irish Cobbler can grow during the spring when soil temperatures are between 45° and 58° F., before mass root invasion by the nematodes occurs. Green Mountain, however, begins to grow when soil temperatures are 54° to 58° F. Varietal differences in susceptibility to nematode damage are probably correlated with varietal differences in ability to produce roots at temperatures below those at which nematode attack takes place. Differences in injury from year to year within a given variety probably depend upon the duration of mild spring temperatures when the plants can grow free of nematode attack.

To illustrate the importance of this varietal susceptibility we have compared the crop yields and cost of production of Irish Cobbler and Green Mountain on clean, on moderately infested, and on heavily infested soils for the years 1941–1944, where our experimental data were available, together with a summary for those years. On the basis of these figures (Table 4) we may conclude that Irish Cobbler may or may not be profitable on infested land, and that Green Mountain definitely is not profitable.

An effort was made to correlate some potato yields of the entire Nassau County, L. I., N. Y., from 1939 through 1944, with our conclusions. To do so it was necessary to combine losses due to *Heterodera rostochiensis* with those

TABLE 5.—*Yields of 2 potato varieties for Nassau County, N. Y., as compared with early spring soil temperatures*

Year	Yield in cwt./acre		No. wks. with soil temperature at	
	Irish Cobbler	Green Mountain	45°–58° F.	54°–58° F.
1939	96	73	3	0
1940	191	161	8	4
1941	139	133	5	4
1942	192	144	4	3
1943	141	111	6	2
1944	102	84	5	0

due to *H. marioni,* since temperatures at which the latter invades roots *en masse* according to Godfrey[5] are nearly identical with temperatures of invasion by the former. Table 5 gives a comparison of the average yields of Irish Cobbler and Green Mountain in Nassau County for these years, together with the number of spring weeks during which the mean soil temperatures there were 45° to 58° F. and 54° to 58° F. The year 1940 was a banner year for potatoes from the standpoints of both county yield and duration of root-growth before nematode attack. On the other hand, the years 1939 and 1944 were characterized by low yields and, significantly, a short period of mild spring temperatures. It seems possible that the length of the period of mild spring weather is a major factor in determining crop production in areas infested with either *H. rostochiensis* or *H. marioni.*

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THE FUNGUS THAT CAUSES SOOTY STRIPE OF SORGHUM SPP.

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The fungus discussed in this paper causes elongate-elliptical lesions on leaves of sorghum and related species (Fig. 1). It occurs in a number of the Southern States, in some cases in considerable abundance.

Larsh (7) in 1944 reported *Septorella sorghi* Ell. and Ev. on sorghum from Oklahoma and Arkansas. Subsequently (8) this identification was corrected to *Titaeospora andropogonis* (Miura) Tai, which is the name usually applied to the fungus that causes sooty stripe of sorghum. As the writers were unfamiliar with *Septorella sorghi,* a specimen was requested and material collected in Oklahoma was kindly sent by D. A. Preston. The Oklahoma material agreed perfectly with that collected previously by one of the writers (Lefebvre) at a number of points in several Southern States.

It has been assumed, heretofore, that the first description of the pathogen was that given by Miura (9) in 1920, when he described it on "*Andropogon sorghum* Brot. var. *vulgaris,* subsp. *japonicus* Hack." (*Andropogon sorghum* (L.) Brot. subsp. *sativus* Hack. var. *vulgaris* Hack. subvar. *japonicus* Hack. = *Sorghum vulgare* Pers.). Miura created a new genus for the fungus and called it *Ramulispora andropogonis.* He placed the genus in a new subfamily of the Melanconiales. Tai (11), in 1932, transferred the species to the previously described genus *Titaeospora* Bubák (4), another genus of the Melanconiales, making the name *T. andropogonis* (Miura) Tai. This is the name by which the fungus had been known up to 1944 when Larsh (7) reported on *Septorella sorghi.*

In 1903, Ellis and Everhart (5) described *Septorella sorghi* on the leaves of *Sorghum halepense* (L.) Pers. collected by George W. Carver at Tuskegee, Alabama, in September, 1901. A part of the type collection of this fungus was kindly supplied by J. C. Gilman from the herbarium of Iowa State College. An examination of the fungus showed that it was identical with the one described by Miura (9). Thus, *S. sorghi* Ell. and Ev. antedates *Ramulispora andropogonis* Miura by 17 years. Ellis and Everhart, however, had mistaken the sclerotia for pycnidia, and apparently had not noticed that the conidia were branched.

In two recent papers, Bain (2) and Bain and Edgerton (3) have pointed out that the fungus has been incorrectly classified and that the fruiting body

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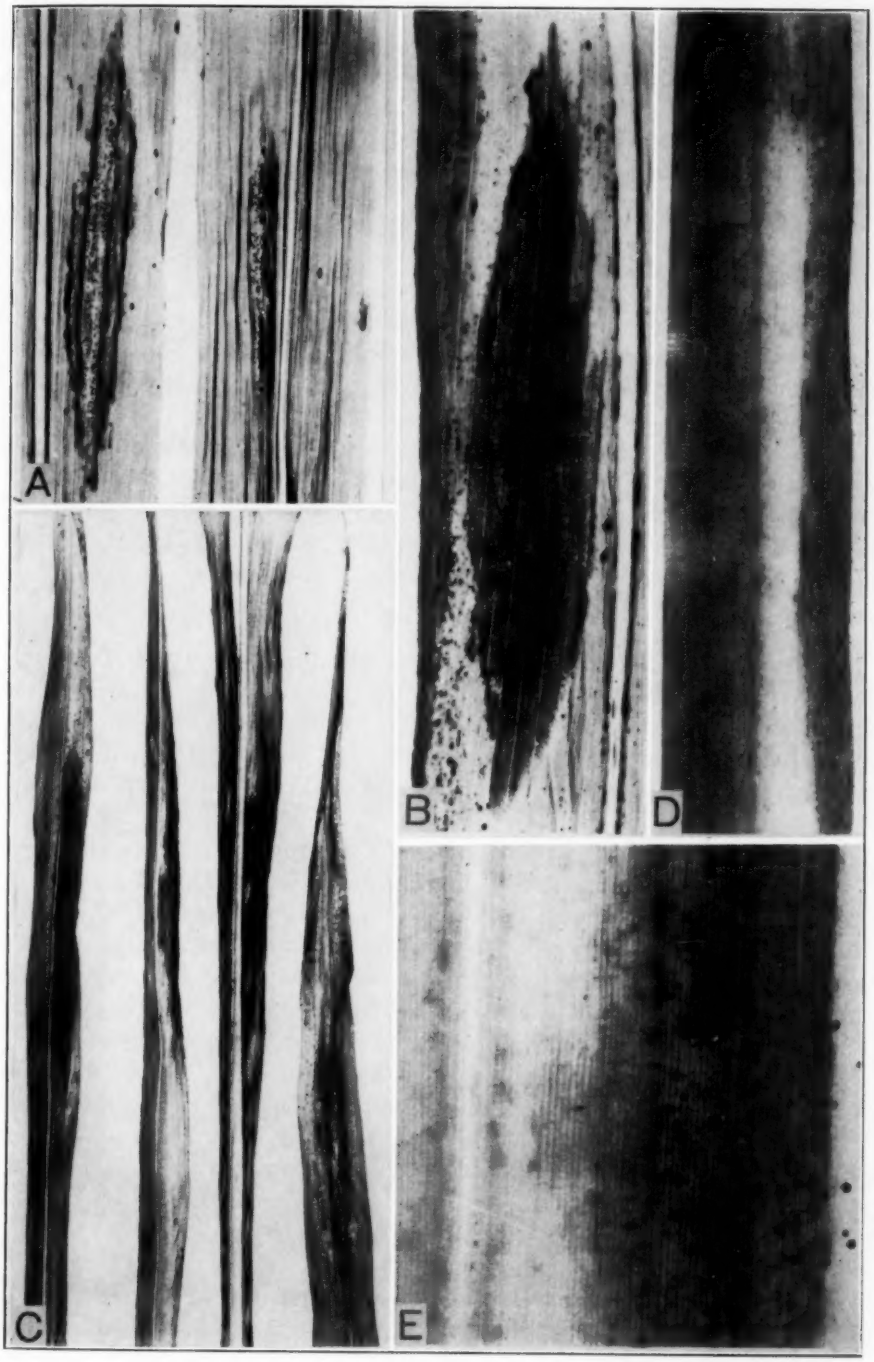

FIG. 1. Lesions of the sooty stripe disease on sorghum. A and B, Lesions on sorghum leaves collected in the field; C, Lesions produced by inoculation in the greenhouse; D, Lesion produced by inoculation, showing sclerotia; E, Part of the same lesion as D, enlarged.

actually is more like a sporodochium than an acervulus. The studies by the writers agree with this.

In an attempt to determine the relationship of *Septorella sorghi* and *Titaeospora andropogonis* and to establish the systematic position of these fungi in the Fungi Imperfecti, all of the above-mentioned material and other herbarium specimens were studied, as well as fresh material from plants artificially inoculated in the greenhouse. Studies were made also to obtain a better knowledge of the life history and parasitism of the fungus that causes the sooty stripe disease.

DISTRIBUTION OF THE FUNGUS

The fungus has been found on the following hosts in the States indicated. The reports not credited are based on specimens collected by one of the writers (Lefebvre).

On *Sorghum halepense* (L.) Pers., Alabama (5), North Carolina, Mississippi; on *S. vulgare* Pers., Alabama, Arkansas (7), Florida, Georgia, Louisiana (1), Mississippi (10), Oklahoma (7); on *S. halepense* × *S. vulgare*, Mississippi; on *S. vulgare* var. *sudanense* (Piper) Hitchc., Florida, Georgia, Texas; on *S. vulgare* × *S. vulgare* var. *sudanense*, Georgia.

MORPHOLOGY OF THE FUNGUS

The mycelium, stromata, sporodochia, conidiophores, conidia, and sclerotia have been studied chiefly on field and greenhouse material of sorghum in variously stained free-hand and microtome sections of lesions. Phloxine in Patterson's mounting fluid has been found satisfactory for hand sections, and safranin and fast green for microtome sections. Unstained dried and fresh material also has been studied.

The hyphae are chiefly intercellular in the parenchyma of the leaf tissue (Fig. 2, C) but are intracellular in the vessels (Fig. 3, C and D). In the vessels, the hyphae extend longitudinally in the leaf, thereby lengthening the lesion. Eventually the hyphae tend to aggregate just beneath the stomata to form more or less compact stromata from which the conidiophores arise (Fig. 2, B and C, and Fig. 4, B). Frequently, the substomatal hyphae, and the conidiophores arising from them, are few and not aggregated into compact masses (Fig. 2, A, and Fig. 4, A). Typically, the conidiophores mass together into a column, which eventually collapses the guard cells (Fig. 2, C, and Fig. 3, A). These conidiophores usually extend to a point somewhat above the epidermis and bear the conidia singly at their tips, and the conidia eventually become aggregated into gelatinous masses (Fig. 4, C). With temperature and moisture favorable for the fungus, the fructifications continue to develop and expand. The stromata, as well as the conidiophores, eventually become sclerotized (Fig. 3, A, and Fig. 4, D). Conidia continue to be produced until all of the conidiophores become sclerotized. The entire fructification may be converted into a black sclerotium which ceases to produce conidia (Fig. 4, E, a). Thus the fruiting structure without question is to be interpreted as a sporodochium.

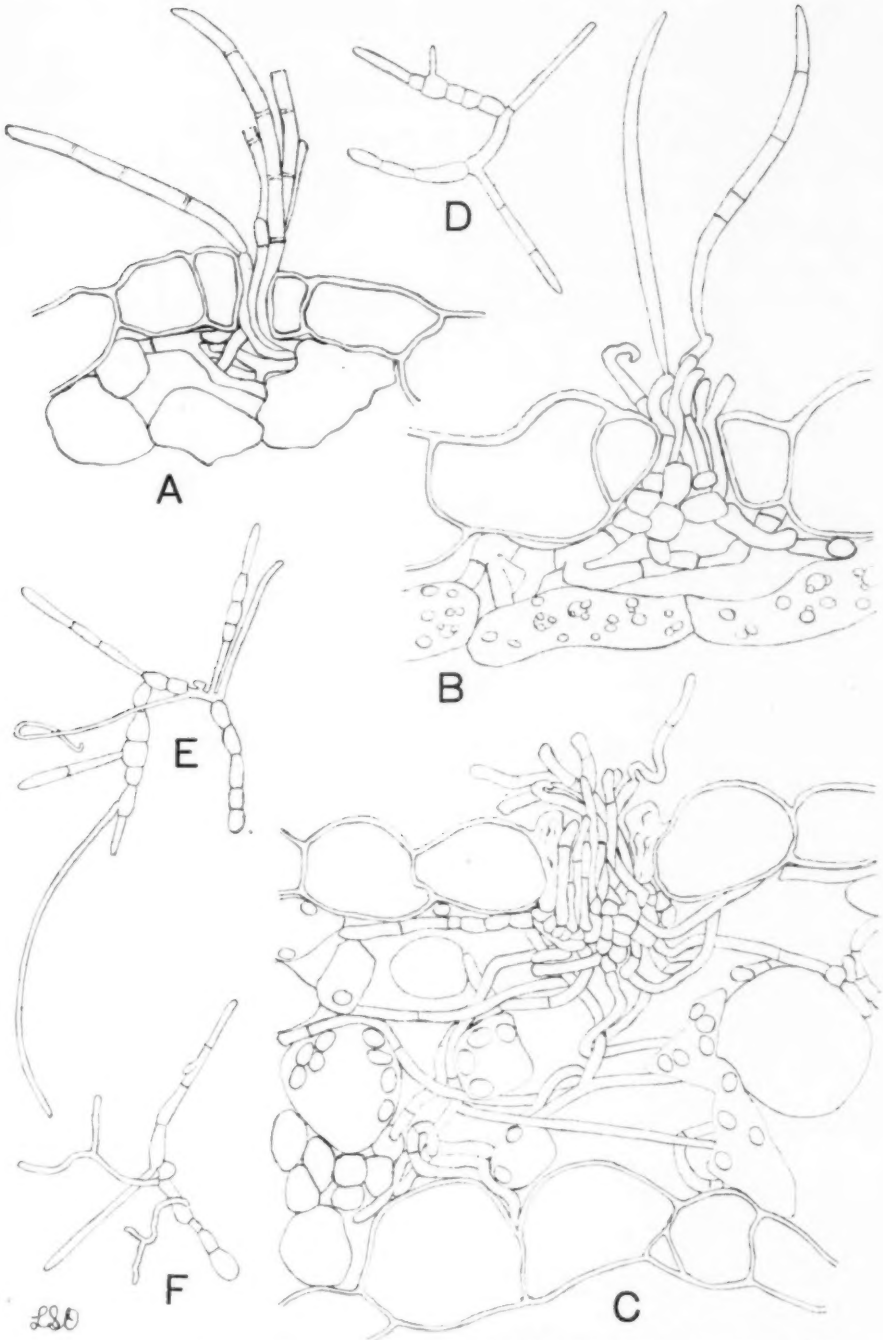

FIG. 2. *Ramulispora sorghi*. A, Small conidial fructification in stoma (Same as Fig. 4, A); B and C, Young sporodochia in stomata (C also shown in Fig. 4, B); D to F, Conidia germinating on agar. (A to C, ×945; D to F, ×400.)

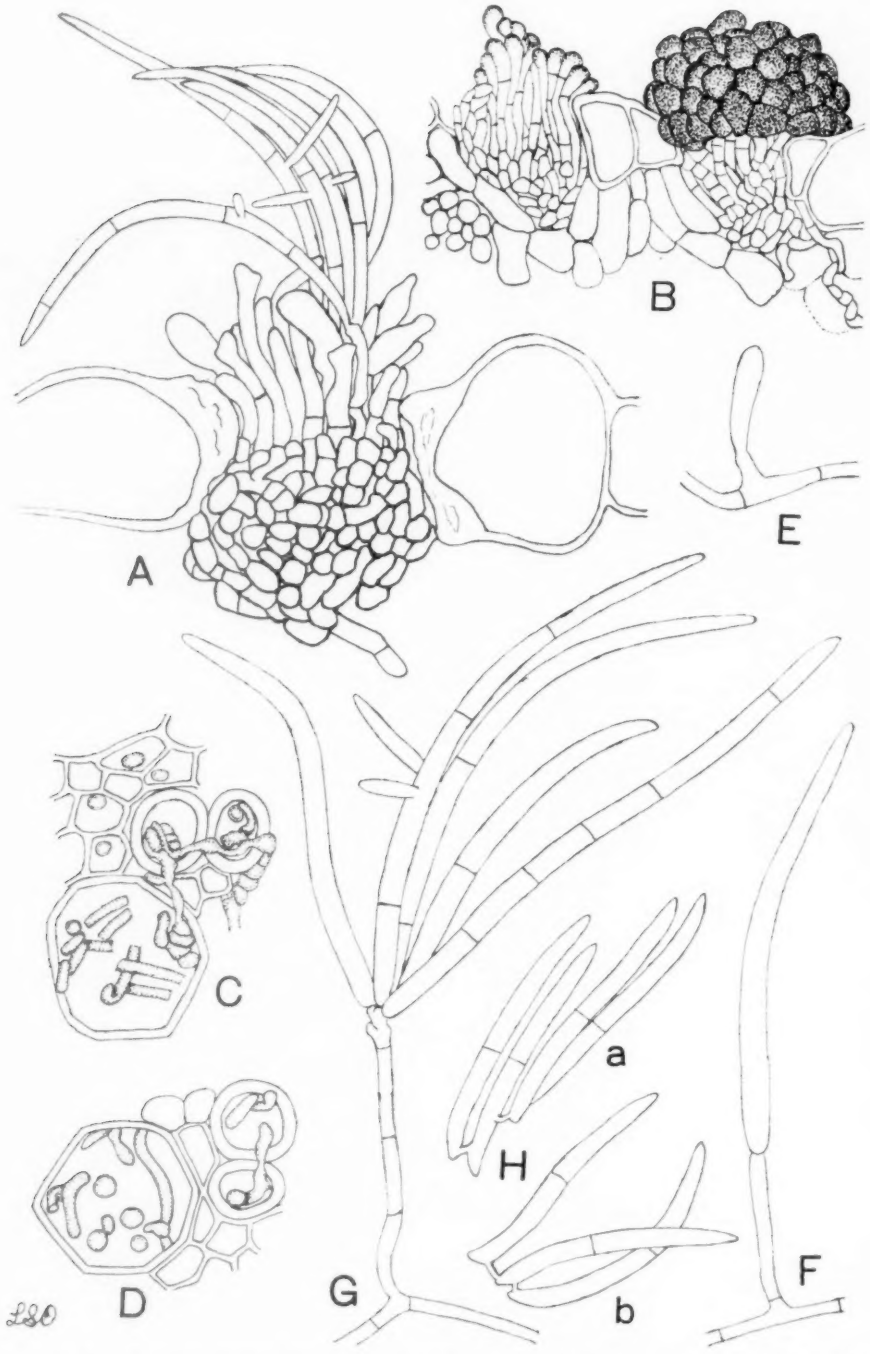

FIG. 3. A to G, *Ramulispora sorghi* on sorghum; A, Sporodochium, showing substomatal stroma, conidiophores, and branched conidia; B, Developing sclerotia; C and D, Hyphae in the vessels; E to G, Conidiophores and conidia as they appear inside the agar medium; H, a and b, Fused conidia of *Titaeospora detospora*. (All figures ×945, except B, ×450.)

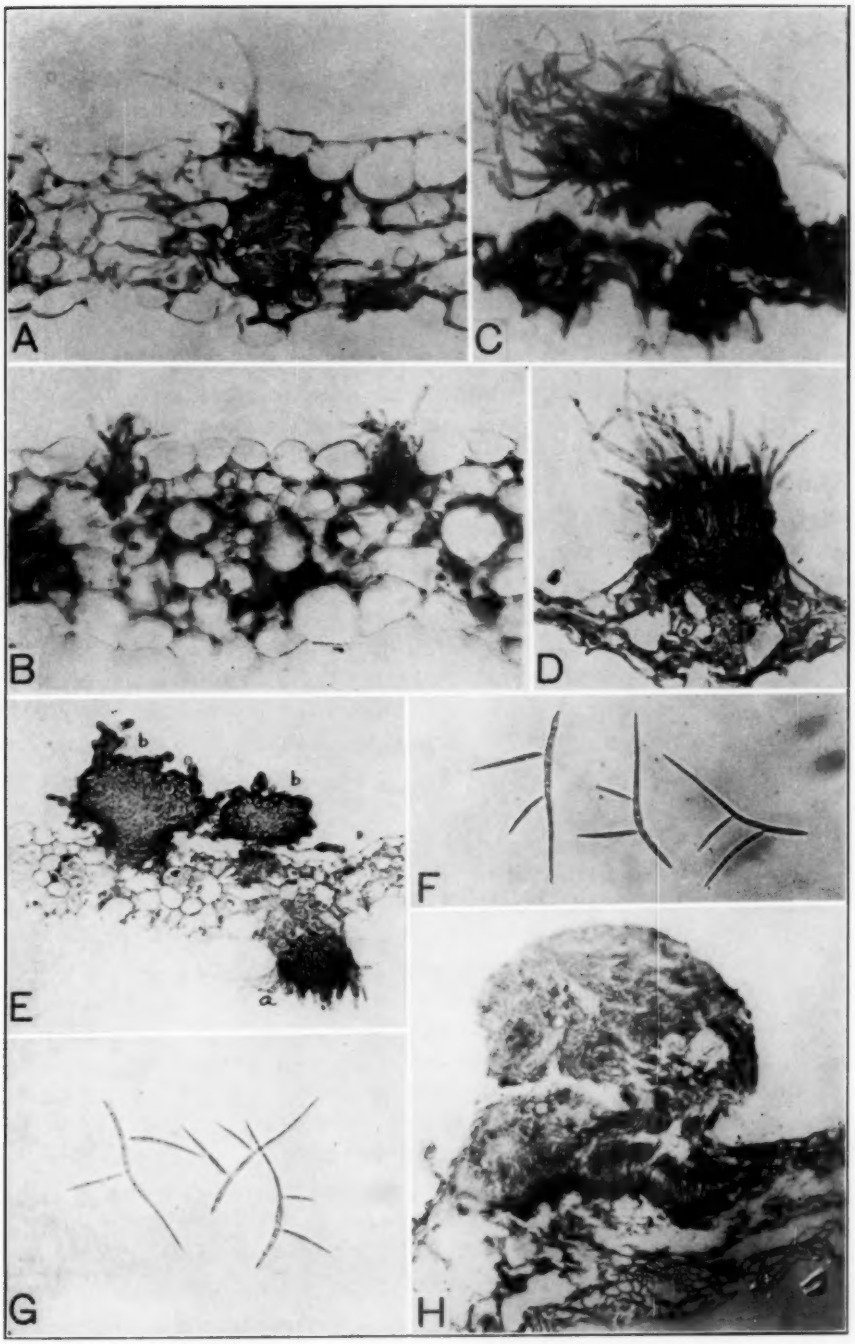

FIG. 4. Photomicrographs. A to G, *Ramulispora sorghi* on sorghum; H, *Titaeospora detospora* on *Equisetum;* A, Small conidial fructification; B, Two young sporodochia; C, Sporodochium with mass of conidia; D, Mature, partly sclerotized sporodochium with conidia; E, Sclerotized sporodochium (a) and two sclerotia (b); F and G, Conidia; H, Acervulus of *Titaeospora detospora* with exuding mass of conidia. (All figures ×400, except E, ×155, and H, ×90.)

The conidia are long and slender, hyaline, curved, tapering gradually toward the apex, 38–86.3 × 1.9–3 μ. They become 3- to 8-septate and produce 1 to 3, usually 2, lateral branches, which become 0- to 3-septate and measure 5–53 × 1.1–2.5 μ (Fig. 3, A, and Fig. 4, F and G). When the conidia are germinated on agar, their cells swell, often appear chlamydospore-like, and send out narrow germ tubes (Fig. 2, D to F).

Most of the large black sclerotia that appear on the surface of the lesion seem to arise independently of the sporodochia, although it is not always possible to distinguish between sclerotized sporodochia and young sclerotia. If diseased plants are kept in an environment unfavorable for conidial production, only sclerotia appear, and many of these seem to develop from what would have been sporodochia. In fact, if the lesions are placed in a moist chamber at this stage, some of the immature sclerotia produce conidia very readily. After the sclerotia have matured fully, however, they usually cannot be induced to produce conidia.

In descriptions from the Orient, the sclerotia have been described as occurring only in autumn (9, 11). In a collection sent by M. L. Lohman from Mississippi, they were produced as early as June 11. Other records show that in the United States they appear throughout the summer and autumn. Their occurrence is dependent, not so much on the time of the year, as on the condition of the dying, diseased tissue.

The sclerotia, like the sporodochia, arise from the sub-stomatal stromata that give rise to columns of hyphae that pass through the stomata and form hemispherical masses of enlarged hyphal cells on the surface of the leaf (Fig. 3, B, and Fig. 4, E, b). The entire structure becomes sclerotic. At maturity, the hemispherical bodies are brittle and easily broken off and dislodged from the leaf surface. These sclerotia are hard, black, and tuberculate and measure 53–170 μ in diameter.

In order to determine how the fungus overwinters and how infection occurs the following spring, some heavily infected leaves that were covered with sclerotia were placed outdoors and left there through the winter of 1944–45 at the Plant Industry Station, Beltsville, Maryland. On May 22, 1945, some of the material was brought in and examined microscopically. The sclerotia were unchanged and live conidia were almost completely lacking. Some of the leaf fragments with numerous sclerotia on them were placed on moist blotting paper in a Petri dish and left overnight. The following day, many of the sclerotia were producing conidia in great profusion. Gelatinous aggregates of conidia, like those already described, were observed. Free-hand sections of the material showed that the conidia were being produced chiefly at the top of the sclerotium where a group of conidiophores had appeared. Although the conidia are produced entirely outside the sclerotium, the latter appears, superficially, like a pycnidium with conidia exuding from an ostiole. Some conidia were observed arising from sclerotia that had been arrested early in their development. Thus it appears that the sclerotia function primarily in overwintering the fungus and that the conidia produced by them are the chief source of infection in the spring.

CULTURAL CHARACTERISTICS OF THE FUNGUS

The fungus was grown on various culture media including malt, potato-dextrose, prune, corn-meal, bean-pod, and sorghum-leaf agars. In all cases, growth was rather slow. On all agar media, the fungus grew in raised, black, tough, tuberculate masses, appearing somewhat like an aggregation of sclerotia. Several weeks were required for good conidial production. Conidia, similar to those on leaf lesions, were produced abundantly on short conidiophores in light pink, gelatinous, cone-shaped masses all over the rough surface of the black fungal cushions on all agars, except malt agar, on which very few of them appeared.

In agar cultures, a considerable part of the fungal growth was beneath the surface of the agar. In thin sections cut through the interior of the agar, small black specks were observed all through the medium. An examination of these under a microscope showed that they were small aggregates of swollen hyphal cells. Furthermore, the fungus was growing throughout the interior of the agar medium and sporulating there like a moniliaceous fungus. One to several conidia were produced on conidiophores of various lengths, which arose from hyaline hyphae throughout the medium (Fig. 3, E to G). The conidia were typical in appearance, except that usually they were larger than those produced on the sclerotia on the surface of the agar.

Other culture media used were carrot juice plus 1 per cent dextrose, sterilized stems of sorghum and Johnson grass, cowpea pods, and string beans. Again the fungus grew slowly in the form of conspicuous, black, tuberculate masses. Conidia were scarce on all of these media except in the carrot-juice concoction, in which they were produced in abundance.

An effort was made to find the perfect stage in culture, in material from the field, and in overwintered leaves, but without success.

TAXONOMY OF THE FUNGUS

The foregoing investigations have shown that the conidial fructification of the fungus that causes sooty stripe of sorghum, Sudan grass, and Johnson grass is a sporodochium and not an acervulus. This fungus, in some respects, is like *Gloeocercospora sorghi*, recently described by Bain and Edgerton (3) on sorghum. Both fungi have sporodochia and sclerotia; but, as noted above, Ellis and Everhart (5) named the fungus *Septorella sorghi* in 1903, thinking that the fruiting structure was a pycnidium. In 1920, Miura (9) established the genus *Ramulispora* and described this fungus as *R. andropogonis*. In 1932, Tai (11) transferred the species to the genus *Titaeospora* Bubák, making the combination *T. andropogonis* (Miura) Tai.

The genus *Titaeospora* Bubák, which has *T. detospora* (Sacc.) Bubák on *Equisetum* as the type species, has true acervuli (Fig. 4, H). Bubák (4) characterized the genus chiefly by branched conidia produced in acervuli. Von Höhnel (6), however, pointed out that what Bubák had taken for branched conidia in *T. detospora* in reality were not branched conidia but were conidia that were fused at or near their bases. The writers examined

authentic material of *T. detospora* on *Equisetum* and found the same type of conidial fusion as described by Von Höhnel (Fig. 3, H, a and b). This being the case, the fungus that causes sooty stripe cannot go into the genus *Titaeospora,* because its fruiting structure is a sporodochium and it has characteristically branched spores.

Miura (9) described the genus *Ramulispora* as follows:

"Melanconiales

"Melanconiales—Hyaloramulisporae. M. Miura, N. Subf. *Ramulispora* M. Miura, n. g. Spores cylindrical, flexuose, slender, branched, septate, other characteristics as in the case of *Cylindrosporium.*"

To be sure, Miura interpreted the fruiting structure as an acervulus, but the other characters, including the branched conidia, agree perfectly with those of the fungus studied by the writers. The writers, therefore, propose that the generic name *Ramulispora* be retained, but that it be transferred to the Tuberculariaceae, thereby abolishing Miura's sub-family, and that the description of *Ramulispora* be emended as follows:

Sporodochia amphigenous, produced through stomata of infected leaves, arising from sub-stomatal stromata; conidiophores hyaline, simple or branched, short; conidia acrogenous, hyaline, filiform, with lateral branches, produced in gelatinous aggregates; superficial sclerotia present.

Since *Septorella sorghi* Ell. and Ev. is the oldest specific name of the fungus, the following is proposed:

Ramulispora sorghi (Ell. and Ev.) Olive and Lefebvre, Comb. Nov.

Septorella sorghi Ell. and Ev. (5) 1903.

Ramulispora andropogonis Miura (9) 1920.

Titaeospora andropogonis Tai (11) 1932.

Spots elongate-elliptical, with straw-color centers, surrounded by reddish-purple to tan borders according to the variety. Sclerotia amphigenous, gregarious, superficial on straw-color centers of lesions, sub-globose, coarsely tuberculate, subcarbonaceous, 53–170 μ; sporodochia, amphigenous, develop from sub-epidermal stromata, becoming erumpent through stomata; conidiophores fasiculate, 10–35 × 2–3 μ; conidia filiform, with 1 to 3 branches, 5–53 × 1.1–2.5 μ, hyaline, curved, tapering toward apex 38–86.3 × 1.9–3 μ 3- to 8-septate.

On *Sorghum halepense* (L.) Pers.—Alabama, North Carolina, Mississippi.

On *S. vulgare* Pers.—Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Oklahoma.

On *S. halepense* × *S. vulgare*—Mississippi.

On *S. vulgare* var. *sudanense* (Piper) Hitchc.—Florida, Georgia, Texas.

On *S. vulgare* × *S. vulgare* var. *sudanense*—Georgia.

In the original description of the fungus, Miura (9) gave 36–100 × 2–4 μ as the spore measurements, and Tai (11) gave 47.6–106.9 × 2.04–3.06 μ. While these length measurements are somewhat greater than those obtained by the writers, this difference is not considered significant, as the length of spores of this type have a wide range, being influenced greatly by the environment in which they are produced.

PATHOGENICITY OF THE FUNGUS

Typical leaf spots produced by this fungus in the field begin as small, oblong, reddish-purple spots, which develop into conspicuous elongate lesions

with purplish borders and straw-color centers of dead tissue. This dead tissue usually is more or less densely covered with small black sclerotia, which may impart a sooty appearance to the lesion (Fig. 1, A and B), hence the common name sooty stripe given to the disease by Bain (2). The spots are about equally distinct on both sides of the leaf.

In some varieties of sorghum, such as Leoti, and in Tift and Sweet Sudan grass, in which the purple leaf pigment is absent, the lesions have a tan instead of the purple border described above; and on Johnson grass the purple border usually is not so pronounced as in most varieties of sorghum. Mature spots, however, are easily recognized by the numerous sclerotia on the surface of the lesions.

If the lesions are examined with a binocular microscope or even with a hand lens after they have been taken from a warm, moist environment, numerous cones of agglutinated, flesh-color masses of conidia can be seen arising from either leaf surface. Sclerotia in various stages of development also may be scattered over the same area. Both the sclerotia and conidia appear to be somewhat more abundant on the lower than on the upper side of the leaf.

In a nursery of sorghum varieties, kindly arranged for in 1944 by J. D. Warner at the North Florida Experiment Station, Quincy, Florida, very light to moderate infections by *Ramulispora sorghi* were observed on the following varieties: Rex, Planter, Colman, Saccaline, Leoti, Denton, Rox Orange, Sapling, Brown Durra, Norkan, Atlas, Silver Top, and Gooseneck.

To determine whether symptoms similar to those found in the field could be produced in the greenhouse, plants of sorghum and related species were inoculated in the spring of 1945 by spraying four or five times over a period of two days with aqueous suspensions of conidia and hyphae made from cultures of *Ramulispora sorghi* grown on agar or in carrot juice. The latter medium was the most effective in producing large amounts of inoculum.

Three series of inoculations were made. Within a few days after each series had been inoculated, small, scattered, purplish spots appeared on the leaves, but no conspicuous lesions were observed until about 16 to 18 days after inoculations had been made. During this period, the plants were left in the moist chamber most of the time. The lesions were mostly like those observed in the field, although usually they were not so large (Fig. 1, C). When plants with mature lesions were returned to the moist chamber, conidia appeared on the lesions in great abundance. At the same time sclerotia also were readily produced (Fig. 1, D and E). Apparently they were more abundant on plants kept in the moist chamber at this stage, although they developed also on those kept outside the moist chamber.

The relative susceptibility of the sorghum varieties and related species inoculated with *Ramulispora sorghi* may be given tentatively as follows. An accurate interpretation of results, however, was not possible in every case because many leaves on the test plants died or developed streaks before typical lesions were produced. Heavy infection was obtained on Brown Durra; on Orange, Rex, and Sugar Drip sorgho; on White kaoliang; on common and

Tift Sudan grass; and on Johnson grass. Moderate infection occurred on Texas Blackhull kafir; on Saccaline, Minnesota Amber, and on Hodo sorgho; on Standard broomcorn; on Dwarf Yellow and Martin milo; and on Sweet Sudan grass. Light infections resulted from inoculations carried out on Honey, Early Folger, Atlas, Iceberg, and Leoti sorgho; and on Plainsman milo, Spur feterita, and Early Hegari varieties of sorghum. Wherever the large conspicuous lesions appeared, they developed the typical straw-color centers and purple borders, except in varieties where the purple pigment was absent in the leaves.

SUMMARY

The morphology of the fungus that causes sooty stripe of sorghum, Sudan grass, and Johnson grass is described. Mature lesions caused by the fungus usually are covered by numerous black sclerotia, have a straw-color center and are surrounded by a conspicuous purple border. In a moist atmosphere, sporodochia push through the stomata and produce conidia in light pink, gelatinous masses. These conidia are filamentous, curved, and septate, with 1 to 3 lateral branches. Small, black, tuberculate sclerotia also are produced in large numbers through the stomata. The fungus overwinters by means of these sclerotia, which germinate to produce conidia in the spring.

The fungus may be cultured on most artificial media, but develops very slowly. In culture, it grows in the form of raised tuberculate, black masses, on which the conidia appear in light pink, gelatinous aggregates. Inside the agar medium the organism grows and sporulates like a moniliaceous fungus.

Typical lesions with sclerotia, sporodochia, and conidia have been produced readily by inoculating several varieties of sorghum, Johnson grass, and Sudan grass in the greenhouse.

The genus *Ramulispora* is emended and transferred from the Melanconiales to the Tuberculariales of the Fungi Imperfecti and the new combination *Ramulispora sorghi* is made.

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AN UNDESCRIBED EAR ROT OF CORN CAUSED BY PHYSALOSPORA ZEAE[1]

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INTRODUCTION

For the past several years an ear rot of corn (*Zeae mays* L.) has been found in Indiana that could not be identified with any of the known diseases of corn ears. During the period that the disease has been under observation it never has been found in great abundance. In 1944, however, its prevalence reached as high as 10 per cent in some localities in the east-central and southern areas of the State.

The causal fungus remained unidentified for a number of years because it did not produce fruiting structures either on infected ears in the field or in pure culture. Recently it was induced to sporulate on certain media, thereby facilitating its proper identification.

The present paper describes the symptoms of the disease as it affects ears of corn and reports experiments to establish identity of the pathogen.

SYMPTOMS

The first indication of infection is premature bleaching of the husks of the ear. As the disease progresses the fungus mycelium cements the husks to each other and to the kernels. At this stage, the more or less felty, white mycelium is observable on and between the kernels (Fig. 1, A) and, when the ear is broken, the pith of the cob has a characteristic slate-gray discoloration and is dotted with black sclerotia (Fig. 1, H).

As the disease continues to develop, mycelium grows between the husks, over the kernels, and within the cob. The white felty layer of mycelium between the inner husks soon shows irregular blotches and streaks of gray, particularly near the base of the ear (Fig. 1, B). At this stage, when the infection is well developed, the kernels often are speckled because of the formation of black sclerotia beneath the pericarps (Fig. 1, C, D, E). Heavily infected kernels often are black at the tip, the coloration extending for varying distances toward the crown. When ears are kept moist for a long time, as may occur in rainy weather or when the ear is in contact with the ground, or when the ear contains a high percentage of natural moisture, the seed coat has black streaks (Fig. 1, F). Sections through badly infected kernels show the embryo to be completely overrun by black mycelium of the fungus. Beneath the seed coats of such kernels black stromatic layers of

[1] Cooperative investigations between the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, United States Department of Agriculture, and the Department of Botany and Plant Pathology, Purdue University Agricultural Experiment Station. Journal Paper No. 200 of the Purdue University Agricultural Experiment Station.

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mycelium are frequently seen (Fig. 1, G). There is some shredding of the cob at the base of the ear, but this is not so extensive as in Nigrospora cob rot (Fig. 1, I). Completely rotted ears have dark gray husks, and cobs and kernels are reduced to a dry gray-black pithy mass (Fig. 1, B).

Infection takes place generally near or through the butt of the ear, but occasionally ears are found where infection was initiated through the tip.

In many respects this ear rot closely resembles Diplodia ear rot, particularly in initial phases of its development (Fig. 1, A), and the two diseases may easily be confused if superficially observed. The slate-gray color and the presence of black sclerotia in the cob are symptoms distinguishing this disease from Diplodia ear rot in relatively early stages. The gray mycelium

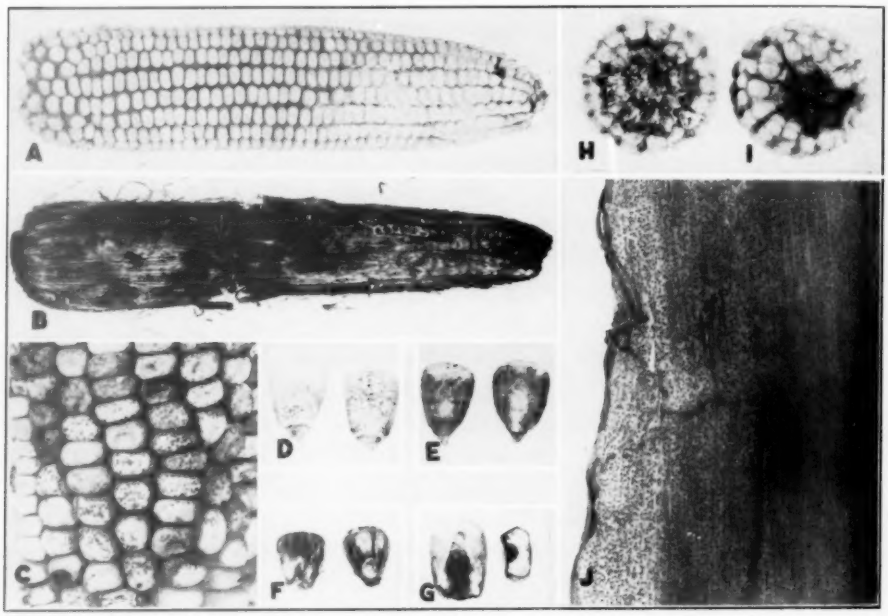

FIG. 1. Typical symptoms produced by the gray-ear-rot fungus. A. Early stage of infection; note similarity in appearance to Diplodia ear rot. B. Advanced stage of the disease, with blotches of gray mycelium between the husks. C, D, E. Speckled crowns and faces of kernels due to sclerotia beneath pericarps. F. Kernels with black striations. G. Badly infected kernel, showing gray-black coloration of the germ and beneath pericarp. H. Cross section through an infected ear, showing development of sclerotia. I. Base of a diseased ear, showing the shredded end of the cob. J. Typical lesion on corn leaf caused by *Physalospora zeae*.

between the husks and the black sclerotia beneath the pericarps of the kernels are features that further differentiate it. In advanced stages, the gray-black color and dry pithiness of completely rotted ears are distinct from symptoms of Diplodia ear rot.

In order to avoid confusion with a Physalospora ear rot occurring in Florida and caused by *Physalospora zeicola* Ell. and Ev., the common name "gray ear rot" is suggested. The name, gray ear rot, is descriptive of the distinctive gray color of the husks and the appearance of the interior of the cob.

ATTEMPTS TO INDUCE THE FUNGUS TO SPORULATE

The ear-rot fungus was grown on a variety of vegetable extract agars including potato-dextrose, corn-meal, malt-extract, oatmeal, Lima-bean, prune, corn-leaf-decoction, and carrot-extract. Plates of each substrate were divided into two groups, one of which was held in the dark, the other in diffuse light. Cultures were incubated in a temperature range of 20° to 24° C. The fungus was also grown on synthetic agars in which the carbon and the nitrogen sources were varied both qualitatively and quantitatively.

With the exception of malt-extract agar, none of these media supported development of any fruiting structures. On malt-extract agar small botryoid masses were found on old cultures that had been incubated for 6 weeks. These masses were carbonaceous clusters of black pycnidium-like bodies bearing minute, elliptical to oblong, hyaline spores that failed to germinate.

A number of investigators (4, 7) have demonstrated the production of fruiting structures by certain fungi when stimulated by the presence of other fungi or bacteria, or their extracts. Accordingly cultures of the gray-ear-rot fungus were seeded on corn-meal-extract, oatmeal, potato-dextrose, and malt-extract agar in direct association with *Diplodia zeae* (Schw.) Lev., *Nigrospora oryzae* (Berk. and Br.) Petch, *Gibberella zeae* (Schw.) Petch, *Gibberella fujikuroi* (Saw.) Wr., and *Helminthosporium turcicum* Pass. In another experiment these same fungi were grown in liquid culture on malt extract, potato-dextrose extract, corn-meal extract, and Czapek's medium. After 14 days these staled media were sterilized by passing through Seitz filters, added to liquefied agar, poured in Petri dishes, and seeded with the gray-ear-rot fungus. In both experiments the cultures were incubated in diffuse light at room temperature (21° to 24° C.) for 6 weeks. Sporulation failed to occur either in direct association with or on media staled by other fungi.

Natural substrates, including whole oats, whole wheat, whole corn, polished rice, corn meal, oat straw, soybean stems, carrot, green bean, and potato tuber plugs, were sterilized and seeded with the ear-rot fungus. These cultures were incubated in diffuse light at room temperature. No fruiting structures were produced on any of these media, with the exception of soybean stems. On the soybean stems the pycnidium-like bodies, mentioned as occurring on aged malt-extract agar and bearing minute nongerminating spores, were sparsely produced.

Young cultures of the gray-ear-rot fungus growing on potato-dextrose agar were irradiated with ultraviolet light provided by a Cooper-Hewitt 4 amp., 900 watt, D.C. lamp. The cultures were held 35 cm. from the lamp and exposed, without filtration, from 10 to 240 seconds. Hyphal tip transfers from the margins of the colonies treated for 10 to 180 seconds grew normally. Transfers from colonies irradiated for 210 seconds ceased to grow 24 hours after having been implanted on fresh agar. Transfers from cultures exposed 240 seconds failed to grow. In none of the surviving cultures did sporulation take place.

Kernels removed from diseased ears were held frozen in ice cubes for 2 days to 4 weeks, after which they were removed and planted in moist chambers or surface sterilized and plated on agar substrates. Portions of diseased ears were partially buried in sand in the greenhouse. Some of these were kept constantly wet, others were alternately moistened and dried. Infected ears were placed on the surface of the soil out of doors for several months during the winter and examined in the spring. None of these treatments of diseased host material stimulated formation of fruiting bodies.

In view of the negative results obtained in attempts to induce sporulation, so as to facilitate identification of the gray-ear-rot fungus, intensive studies on this phase of the problem were discontinued until further leads from field observations might come to light. Although fruiting structures were produced in limited numbers on malt-extract agar and soybean stems, the failure of the spores to germinate precluded completion of the life cycle of the fungus.

THE OCCURRENCE OF PHYSALOSPORA ZEAE STOUT IN INDIANA

In September, 1943, leaves of corn bearing relatively large lesions were found in widely separated localities in the State. These lesions were tan to grayish brown and ranged from 1×2 inches to 4×18 inches. Scattered over the surfaces of the lesions were numerous small, black, erumpent structures suggestive of some type of fruiting body (Fig. 1, J). In several fields examined the tassels and flag leaves of some plants were bleached out and the tassel necks, or uppermost internodes immediately below the tassel, were inclined at an angle. The bleached condition of these parts stood out in marked contrast to the green leaves and upright tassels of healthy plants. Some elliptical lesions on the tassel necks were water-soaked while others were dry and gray-brown. Black structures similar to those on the leaf lesions, were scattered over the surfaces of dry lesions on the tassel necks.

Examination in the laboratory showed these fruiting structures to be immature, but after 7 to 10 days in a moist chamber, pycnidia and perithecia matured. These fruiting structures were tentatively diagnosed as *Macrophoma zeae* Tehon and Daniels, and *Physalospora zeae* Stout. Comparisons with the type specimens of these fungi definitely proved the identity of the Indiana collections.[3] So far as can be determined this is the first record of these fungi in Indiana.

In the lesions on tassel necks were a few pycnidium-like bodies bearing very small hyaline, single-cell, non-germinating spores. These bodies were similar to the structures that appeared sparsely in certain pure cultures of the gray-ear-rot fungus. Their presence on host material infected with *Physalospora zeae* and also in pure cultures of the fungus, suggested that *P. zeae* and the gray-ear-rot pathogen might be related.

Isolates derived from single pycnidiospores of *Macrophoma zeae* and from single ascospores of *Physalospora zeae* were strikingly similar, in cultural

[3] The writer is indebted to Dr. L. R. Tehon for the privilege of examining collections of this material in the herbarium of the Illinois Natural History Survey.

behavior, to each other and also to isolates of the gray-ear-rot fungus. Further observations on the similarity in colony characteristics and growth rate between *M. zeae*, *P. zeae*, and the ear-rot fungus were made on a number of agar substrates. On all the media used, no differences among the three isolates were evident. The characteristic growth habits of the three isolates

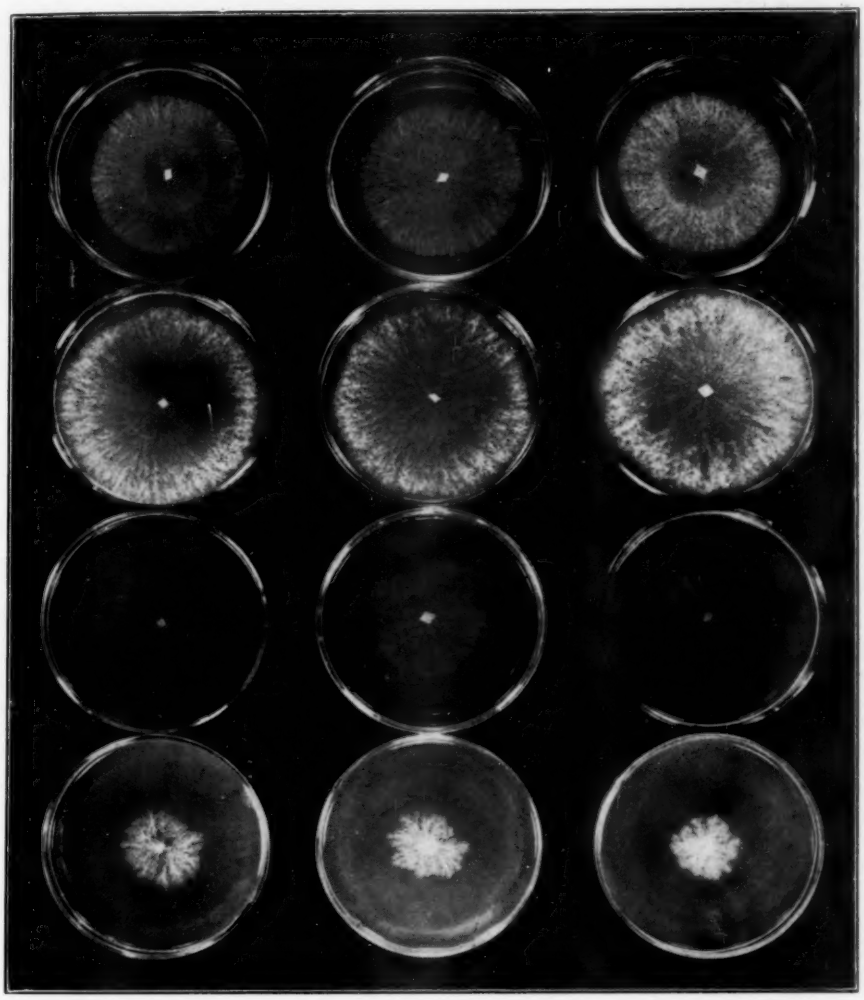

FIG. 2. Comparison of *Physalospora zeae*, *Macrophoma zeae*, and the gray-ear-rot fungus on four agar substrates. Columns, left to right: *P. zeae*, *M. zeae*, and the gray-ear-rot fungus. Rows, top to bottom: Malt-extract agar, potato-dextrose agar, corn-meal agar, and Czapek's-solution agar. Cultures were 40 hours old and had been grown at room temperature, 21° to 24° C.

on four media are shown in figure 2. On potato-dextrose agar these isolates grew very rapidly and a colony held at 21° to 24° C. generally covered the entire surface of the agar in a 9-cm. Petri dish within 48 hours. The mycelium of the young colony is white and of a loose, cottony texture. Within

5 to 8 days, the sub-aerial mycelium turns gray at the center of the colony; and in 14 days the entire colony, when viewed from the bottom of the plate, becomes a dark slate-gray. Later the aerial mycelium becomes progressively darker and assumes a felty texture.

Comparative growth rates of *Macrophoma zeae*, *Physalospora zeae*, and the gray-ear-rot pathogen were obtained on potato-dextrose agar. Because of the relatively rapid growth rate of these isolates, special long tubes were constructed so that measurements of the daily growth of the fungus could be made. The tubes were approximately 15 inches long and each was provided with a depression in the glass on one side near the mouth. This depression served as a dam to hold back the melted agar until it solidified. These tubes provided an agar surface about 12 inches long and ½ inch wide on which the fungus could grow. Tubes were seeded in duplicate, each with a uniform amount of mycelium of one of the three isolates, and incubated at 21° to 24° C. Twenty-four hours were allowed for the transfers to become established and then daily measurements were made of the growth increment. The mean daily growth increment, measured for 8 days, was 32.6 mm. for *P. zeae*, 32.5 mm. for *M. zeae*, and 32.4 mm. for the gray-ear-rot fungus. This similarity in growth rate among the three isolates is further suggestive of their relationship.

In the course of studying *Physalospora zeae*, *Macrophoma zeae* and the gray-ear-rot fungus, it frequently was found that colonies ceased growth 24 to 36 hours after being transferred to fresh agar substrates in Petri plates. Sub-cultures from these colonies also failed to grow.

An experiment was set up to determine the rate of loss of viability among different cultures and factors that might influence it. Several cultures of each of the three isolates were grown in Petri plates on Czapek's-solution agar, Czapek's-solution agar plus 2 per cent autolyzed yeast, 2 per cent malt-extract agar, and potato-dextrose agar. The cultures were replicated 6 times on each medium. Transfers from each young colony were made at 24-hour intervals to fresh plates of the respective agar.

Between the 6th and 10th transfers, all cultures on those media supporting abundant and rapid growth, namely 2 per cent malt-extract agar, potato-dextrose agar, and Czapek's-solution agar plus 2 per cent autolyzed yeast, had died. The cultures carried on Czapek's-solution agar, where growth was sparse and slow, maintained their viability through 30 consecutive daily transfers, after which the experiment was discontinued. The rate of loss of viability appeared to be directly proportional to the rate of growth of the fungus. Isolates can be carried on potato-dextrose agar slants for indefinite periods, if they are not frequently transferred. It may also be pointed out that *Macrophoma zeae* and *Physalospora zeae* in host tissues lose their viability after 12 to 14 months when stored at temperatures and humidities commonly encountered in laboratories. The gray-ear-rot fungus, it has also been found, dies in ears held over 1 year in the laboratory.

EVIDENCE OF THE RELATIONSHIP OF THE GRAY-EAR-ROT FUNGUS TO PHYSALOSPORA ZEAE

The marked similarity of *Macrophoma zeae, Physalospora zeae,* and the gray-ear-rot fungus in cultural behavior, growth rate, loss of viability, and the appearance of a presumably nonfunctional fruiting structure in the life cycles of all three, stimulated further efforts to determine relationship more conclusively.

Single pycnidiospore cultures of *Macrophoma zeae,* single ascospore cultures of *Physalospora zeae,* and mass transfers of the gray-ear-rot pathogen were seeded on sterilized whole wheat, polished rice, corn meal, and corn stalks. Sufficient water was added to prevent drying out. The corn stalks were placed in one-quart Mason jars, the other materials in 250-ml. Erlenmeyer flasks. All cultures were held in a greenhouse where temperatures and light intensities varied over wide ranges.

After about 6 weeks black, spherical bodies were found on the surfaces of the corn stalks. Many of these appeared to have burst, revealing masses of white pseudoparenchymatous tissue. None of the unbroken structures contained spores. At the end of 4 months (January to April) mature pycnidia were first observed. These appeared in all cultures on the sterilized corn stalks (Fig. 3, E). No fruiting bodies were observed on the other substrates. Close examination and measurement of the "second generation" pycnidiospores revealed that in size, shape, and color they were indistinguishable from the spores of *Macrophoma zeae* found on host material collected in the field. Isolates from these pycnidiospores grown in pure culture were identical in cultural behavior and growth rate with cultures of *M. zeae, Physalospora zeae,* and mass isolates from kernels of diseased ears.

The development, in pure culture, of pycnidiospores from isolates originating from single ascospores of *Physalospora zeae* appears to be adequate evidence that *P. zeae* and *Macrophoma zeae* are the sexual and asexual phases of the same fungus. The production of these pycnidiospores, in pure culture, from isolates derived from the gray-ear-rot fungus demonstrates rather conclusively that the heretofore unidentified ear rot is caused by *M. zeae.*

Further evidence of the identity of the ear-rot pathogen was provided by inoculation of corn ears in the field. Inoculum was prepared from young cultures of *Macrophoma zeae, Physalospora zeae,* and isolates from infected ears by macerating the mycelium from each and suspending the hyphal fragments in water. Inoculum was similarly prepared from cultures grown from "second generation" pycnidiospores. Each of the suspensions derived from the sources described were injected, by means of a hypodermic needle, into 30 to 60 ears of a single-cross hybrid on August 3, 1944, one week after the hybrid came into full silk. Final examination of the inoculated ears was approximately 80 days later.

Infection followed all inoculations and no differences were observable in the symptoms produced. The symptoms on artificially inoculated ears were indistinguishable from those on naturally infected ears.

THE CAUSAL FUNGUS

In 1927 Tehon and Daniels (11) adequately described *Macrophoma zeae* and the leaf symptoms produced by the fungus. The measurements and descriptions given by these authors are: Pycnidia round to oval or even lenticular in cross section, spherical to applanate in longitudinal section, developing in and occupying the mesophyll, membranous becoming carbonous with age, 65–120 μ in diameter; ostiole protruding hypophyllously, usually through a stoma, nonrostrate, oval, 28–35 × 15–17 μ. Spores continuous, hyaline to greenish, fusiform, 17–31 × 6.5–8.5 μ.

The measurements of material collected in Indiana (Fig. 3, B, D) are as follows: Pycnidia round to oval, 75–150 μ in diameter, found in the meso-

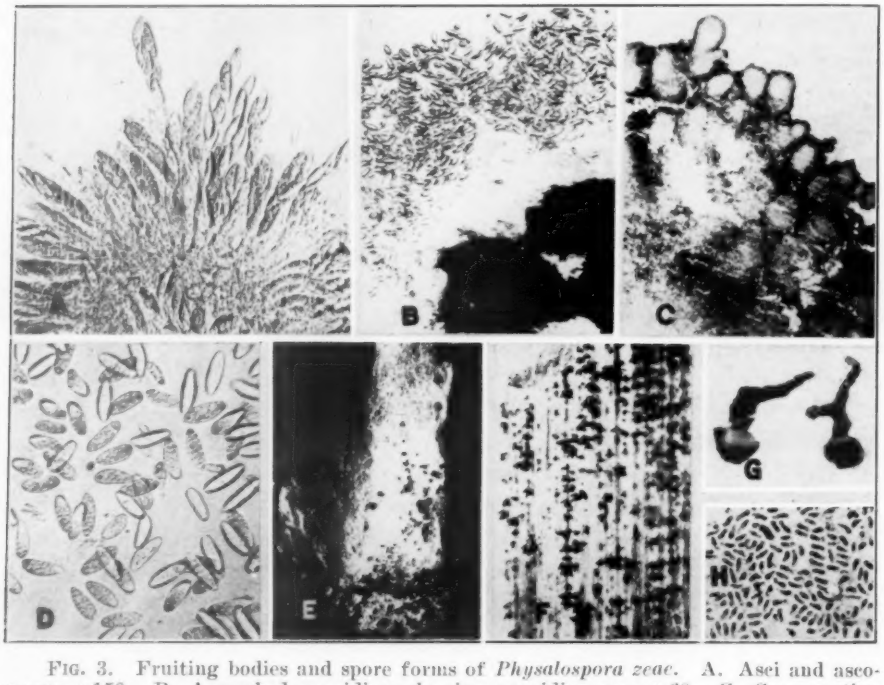

FIG. 3. Fruiting bodies and spore forms of *Physalospora zeae*. A. Asci and ascospores, × 150. B. A crushed pycnidium showing pycnidiospores, × 60. C. Cross section of a cluster of pycnidium-like structures produced on malt-extract agar, × 15. D. Pycnidiospores, × 200. E. Mature pycnidia on the surface of a corn stalk in pure culture, × 2. F. Surface view of an infected tassel after 10 days in a moist chamber, showing development of pycnidium-like structures, × 6. G. Pycnidium-like structure dissected out of host tissue, × 25. H. Nongerminating microspores (stained), × 400.

phyll, carbonous, and ostiole protruding hypophyllously. Spores 1-cell, oval to fusiform, hyaline to dilute greenish amber, 15–38 × 7–14 μ (mean = 27.1 × 10.2 μ). The differences noted here between the Indiana material and that of the original description are very small and may be accounted for by the normal variation expected.

Stout (10) in 1930 described *Physalospora zeae* and the symptoms it produces on corn leaves. He observed the association between *P. zeae* and

Macrophoma zeae in the same lesion and suggested that they may be perfect and imperfect stages. No cultural experiments were done to prove this connection definitely. The measurements and descriptions given by Stout for *P. zeae* are as follows:

Perithecia located in mesophyll, opening by a minutely papillate ostiole, externally carbonous, globose, 75–235 μ in diameter. Asci cylindrical, straight to curved, stalked, double-walled, outer wall thickened especially at the apex, 85–150 × 13–22 μ. Paraphyses obscure, hyaline, filamentous. Spores 8 per ascus, arranged sub-biseriately, hyaline to very dilute olivaceous, 1-cell, narrow ellipsoid, 19–25 × 6.5–8 μ.

The Indiana material (Fig. 3, A) had the following characters: Perithecia developed in mesophyll and protruding by a short neck, carbonous, globose, 80–250 μ in diameter. Asci cylindrical to long clavate, hyaline, double-walled, outer wall thickened at the apex, 8-spore, but occasionally 4- to 6-spore, 90–175 × 12–18 μ. Paraphyses sparse, hyaline, filamentous, apparently branched. Spores narrow ellipsoid, tapering to narrow rounded ends, hyaline to very dilute amber, arranged obliquely in a sub-biseriate order in the ascus, 21–33 × 8–11 μ (mean = 26.8 × 10.0 μ).

The pycnidia produced in pure culture from isolates derived from single pycnidiospores of *Macrophoma zeae*, single ascospores of *Physalospora zeae*, and from mass isolates from diseased kernels differed in certain respects from those occurring on host leaves. In pure culture the pycnidia were produced in clusters on the surface of the substrate (Fig. 3, E). In nature the pycnidia are scattered and sub-epidermal, with only short necks protruding. It is interesting to note in this connection that Nishikado (8) was able to grow pycnidia of *M. reniformis* (Vialo and Ravaz) Cav. in pure culture, and observed a difference in growth habit and structure from those arising in nature on infected host tissue. This author points out, however, that pycnidiospores developed in pure culture were identical with those found in nature. The "second generation" pycnidiospores of *M. zeae* grown in pure culture corresponded very closely in all respects to those occurring on diseased leaves in the field. The spores measured 14–33 × 8.7–14 μ, with mean of 26.2 × 10.6 μ.

The pycnidium-like structures occurring on host material in the field (Fig. 3, F, G) may be described as follows: Pycnidia occurring in mesophyll, carbonous, globose, 150–250 μ in diameter, protruding with a long neck, sometimes bifurcate and rarely trifurcate. Microspores numerous, hyaline, 1-cell, 2–4.8 × 1–2 μ (mean = 4.0 × 1.6 μ), exuded in droplets of a hyaline mucous-like matrix, nongerminating (Fig. 3, H).

The structures occurring in pure culture on aged 2 per cent malt-extract agar and on sterilized soybean stems were slightly different (Fig. 3, C). These were found in clusters on the surface of the substrate and were without the prominent necks found in nature. The size, shape, and color of the microspores, as well as the characteristic of failing to germinate, were the same as those found on host material. The differences between these bodies

as developed in pure culture and as found on the host are of the same order as those between the functional pycnidia found in pure culture and those found on leaves in the field.

It appears reasonable to conclude that these structures are a spore form in the life cycle of *Physalospora zeae*, since they were found both in pure culture and on collections of host material. Because the spores did not germinate, continued observation on the life cycle, using these spores as a point of origin, has thus far been impossible, and the contention that they are a part of the life cycle cannot be irrefutably proved.

Preliminary observations on these apparently nonfunctional pycnidia indicate that environment may play an important part in determining their abundance. When host material was kept constantly wet in a moist chamber and under low light intensities few of these structures were produced. When material from the same lesion was placed in a moist chamber, in a greenhouse where drying out of the chamber frequently took place and light intensity was high, large numbers of these bodies were produced and functional pycnidia and perithecia developed only sparsely.

DISCUSSION

Gray ear rot has occurred sparsely in Indiana since 1939 and specimens have been collected in other sections of the Corn Belt. In 1944 the gray ear rot was widely distributed in the southern and east-central areas of the State where, in some localities, its prevalence ranged up to as high as 10 per cent.

The geographical range of the disease is unknown, but it seems likely that it will be found scattered over an appreciable portion of Eastern United States. Hoppe (5) has reported annually on the relative prevalence and geographical distribution of corn ear rots for the period from 1933 to 1942. In these reports he cited a nonsporulating unidentified fungus which occasionally reached appreciably high percentages in samples of corn collected from terminal markets on the Atlantic Seaboard. He also reported this fungus in corn samples from the Corn Belt and a few Southern States. Cultures of this fungus and of *Physalospora zeae* have been exchanged with Hoppe and have been found to be very similar in appearance and growth rate. While cultural behavior cannot be employed as positive evidence that the fungus isolated by Hoppe is *P. zeae*, yet the similarity is suggestive.

In 1933 Eddins and Voorhees (3) reported *Physalospora zeicola* Ell. and Ev., the perfect stage of *Diplodia frumenti* Ell. and Ev., as a pathogen of corn ears and stalks. This organism differs distinctly from *P. zeae* in the symptoms it produces on ears and in its morphology. The asci of *P. zeicola* measure 95–140 × 10–13 μ, the ascospores 13–27 × 6–11 μ. The asexual stages of these species are strikingly different from each other. The pycnidiospores of *D. frumenti* are dark, striate, and 2-cell; those of *Macrophoma zeae* are hyaline, smooth-wall, and 1-cell.

The association of the genus *Physalospora* with asexual stages in the genus *Macrophoma* has been pointed out in a number of instances. Bonar (2), by means of cultural experiment, demonstrated the connection between

P. ilicis (Schleicher) Sacc. and *M. ilicella* (Sacc. and Penz.) Berl. and Vogl. Nose (9) proved *M. kuwatsukaii* Hara to be the pycnidial stage of *P. piricola* Nose.

The rôle, if any, of the microconidia found in *Physalospora zeae* is unknown. Although all attempts to germinate these spores in water or nutrient solution have been unsuccessful, it is possible that they may serve as spermatia and are able to fertilize receptive bodies, as yet unobserved, that continue their development as ascocarps. On the other hand, they may have served as a fertilizing organ which, in the course of evolution of the species, has lost its function and is unnecessary for the propagation of the fungus. It is interesting to note that Jaczewski (6) mentions the presence of microconidia (5–5.5 × 0.5–0.7 μ) in *P. baccae* Cav. and their failure to germinate. He considers these spores of doubtful significance in the spread of the fungus. Bensaude (1), on the other hand, was able to germinate the microconidia of this fungus and grow normal cultures from them. These cultures produced macroconidia similar to those encountered on the infected host.

The factors favoring spread and development of gray ear rot are not well understood at the present time. During 1944, when the disease reached the highest prevalence yet observed, weather conditions were generally dry throughout mid-summer. In those areas where the disease occurred in greatest abundance, appreciable rain fell during the latter half of August. It is possible that the summer drought favored conservation of inoculum until after silking when ears were in a receptive stage for infection. Further studies are needed to determine more precisely the factors influencing the prevalence of both the ear rot and leaf blight phases of this disease. It is unknown whether overwintering inoculum on the leaves is delayed in maturing until ears are formed or whether 2 generations of spores are produced, the second of which infects the ears. It seems reasonable that the chief source of inoculum infecting ears arises from leaf infections, either those of the previous year or of the current season. Evidence to this effect was seen in 1944 in a field in which 10 per cent or more of the ears were diseased. In November this field had an abundance of infected leaves bearing immature perithecia and pycnidia.

No control for the disease can be suggested at this time, other than the plowing under of infected corn residues. This method of control would be effective only if it were practiced by whole communities, since spread of the fungus can conceivably take place easily from field to field. If a means were known of producing large volumes of spores in pure culture, some progress might be made in differentiating resistant and susceptible inbred lines under conditions of artificially induced epidemics. Under the present circumstances, observation on the relative resistance of inbred lines and hybrids will have to be made under conditions of natural infection.

SUMMARY

The occurrence of an ear rot of corn, heretofore unidentified, is reported and its symptoms described in detail. A common name, gray ear rot, is sug-

gested, it being descriptive of the gray color of the husks and the pith of the cob.

Experiments were designed to induce the fungus associated with gray ear rot to sporulate in pure culture in order to facilitate proper identification.

In Indiana *Physalospora zeae* occurs on corn leaves and on upper internodes of the stalk below the tassel. *P. zeae* and the gray-ear-rot fungus resembled each other in cultural behavior, growth rate, and loss of viability in culture and in specimens of host material.

Cultures of the gray-ear-rot fungus and of *Physalospora zeae* grown on sterile corn stalks produced pycnidia and pycnidiospores identical with those of *Macrophoma zeae*, strongly suggesting that the gray-ear-rot pathogen is *M. zeae*, and that the latter is the asexual stage of *P. zeae*.

Further evidence of this relationship was obtained in field inoculations of corn ears, in which symptoms caused by *Physalospora zeae* were indistinguishable from those developed on ears artificially inoculated with *Macrophoma zeae* or with isolates from naturally infected ears.

A third, heretofore unrecognized, pycnidium-like fruiting structure, is believed to be a stage in the life cycle of *Physalospora zeae*.

The distribution of the disease, factors affecting its prevalence and severity, and the relationship of the fungus which causes it to other species of *Physalospora* are discussed.

No control for the disease is suggested, other than clean cultural practices.

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A NEW HYPHOMYCETE PARASITIC ON A SPECIES OF NEMATODE

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(Accepted for publication October 1, 1945)

In a paper published in 1941 (2), I described as new 10 nematode-destroying hyphomycetes found occurring in leaf mold and other decaying vegetable materials originating from several localities in Maryland, Virginia, and Wisconsin. Though these fungi and their biological relationships are not visible by direct examination of the opaque natural materials, they could be studied quite conveniently in transparent maize-meal-agar cultures which, after being permeated with *Pythium* mycelium, had been further planted with small quantities of the partly decomposed detritus harboring the fungi. They all operate in a typically parasitic rather than predaceous manner: their conidia become affixed externally to the host eelworms by adhesion, and then individually thrust a germ tube through the integument to invade the fleshy interior with an assimilative mycelium. The 4 species presented under the binomials *Acrostalagmus bactrosporus, A. oboratus, Cephalosporium balanoides,* and *Spicaria coccospora* closely resemble the insect parasites assigned to the same genera, except that their display of reproductive parts is far less luxuriant, owing to the much smaller size of the animals serving them as hosts. There is good reason to hold that these 4 species are intimately related to the series of entomogenous forms distributed among *Acrostalagmus, Cephalosporium, Spicaria,* and such allied genera as *Verticillium, Cladobotryum,* and *Beauveria.* They would seem truly kindred taxonomically to the species of *Beauveria* and *Spicaria,* for example, which because of destructiveness to the maize borer (4), the maize earworm (1), the pine bark beetle (3), and various elm insects (5), have in recent times received attention in the pages of this journal.

A fifth nematode-destroying hyphomycete of similar kinship developed abundantly in more than a dozen maize-meal-agar plate cultures that after being overgrown with mycelium of *Pythium ultimum* Trow had been further planted with small quantities of partly decayed crabgrass (*Digitaria sanguinalis* (L.) Scop.) refuse collected from several weed piles near a community vegetable garden in Arlington, Virginia, on April 25, 1944. Although several species of nematodes present in the decaying refuse multiplied freely in the cultures, the fungus apparently restricted its attack to eelworms belonging to a single species, which Dr. G. Steiner has kindly identified as *Panagrolaimus subelongatus* (Cobb) Thorne. Growth of the parasite within infected specimens could not be followed successfully while invasion was progressing, as all fleshy host structures, except the conspicuously resistant oesophagus and oesophageal bulb, soon undergo globuliferous degeneration

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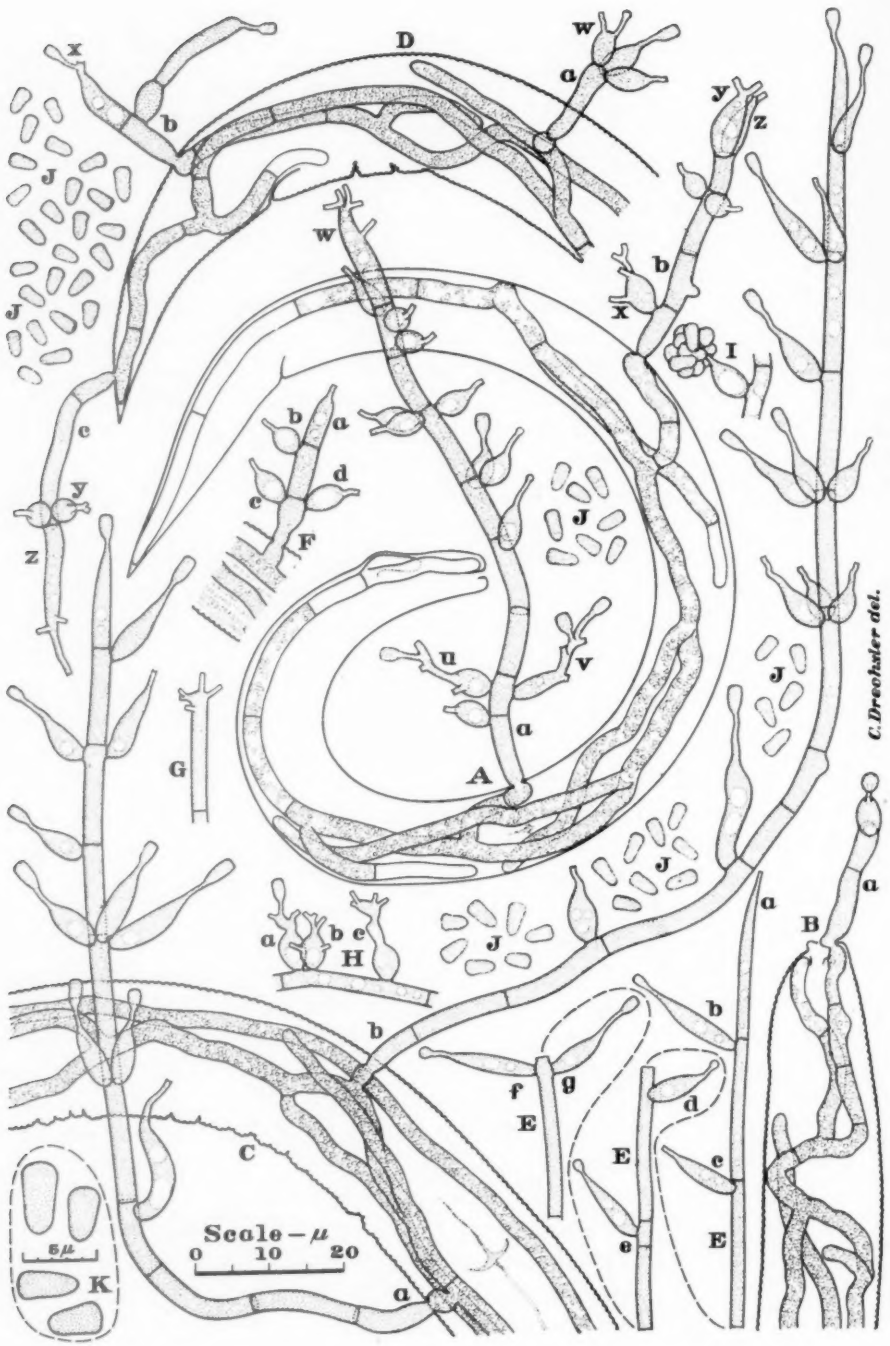

FIG. 1. *Acrostalagmus zeosporus*, drawn to a uniform scale with the aid of a camera lucida. Magnification: A–J, ×1000; K, ×2000.

and thereby offer optical difficulties that prove all the more troublesome since the contents of the young hyphae are likewise pronouncedly globuliferous. After the host contents, apart from the rather slowly evanescent oesophagus and bulb, have been largely assimilated by the fungus, and have been utilized for the production externally of conidiophorous filaments (Fig. 1, A, a, b; B, a; C, a, b; D, a–e), the assimilative mycelium is more clearly discernible. In small eelworms it may consist only of a single axial filament extending from head to tail, together with half a dozen branches of variable lengths (Fig. 1, A). Animals of greater dimensions show correspondingly more profuse hyphal development (Fig. 1, B, C), though in these also the tapering tail is usually occupied by only a single filament (Fig. 1, D). As long as the hyphae remain densely filled with globulose contents few cross-walls can be seen in them (Fig. 1, C). It is uncertain whether at this stage cross-walls are actually few or whether they are in large part obscured owing to the nature of the protoplasm wherein they are immersed. At all events, after the hyphal contents have suffered some reduction in density from the continuous transfer of substance required for formation of conidial apparatus, partitions may be distinguished at fairly close intervals (Fig. 1, A, B). Before long, further transfer of substance entails complete withdrawal of contents from terminal segments of the mycelium (Fig. 1, A, D), and thereupon evacuation of other segments proceeds until the empty host integument surrounds only the equally empty and rapidly evanescent envelopes of the assimilative filaments.

As in allied forms the character of the conidial apparatus produced by the fungus is greatly influenced by positional relationships to the substratum. In instances where the animal host has succumbed on the surface of the substratum the conidiophorous hyphae may at once grow erectly or ascendingly into the air (Fig. 1, A, a, b; D, a; F); or they may grow procumbently for some distance, and then continue their further growth ascendingly (Fig. 1, C, a, b); or, again, they may conclude their growth while still procumbent throughout their length (Fig. 1, B, a; D, b, c). In instances where the animal host has succumbed under the substratum, but not in a deeply submerged position, the conidiophorous hyphae usually make their way to the surface, often by widely divergent paths, before giving rise to conidiiferous branches, or phialides, from their prostrate or their ascending prolongations. Where, however, the animal has succumbed deep under the substratum the conidiophorous hyphae mostly fail to reach the surface, and will then give rise to phialides in submerged positions. Submerged and prostrate portions of conidiophorous hyphae show generally a rather widely spaced arrangement of phialides; many of the segments here being sterile, many others bearing only a single phialide (Fig. 1, B, a; C, b; E, a–e), and few bearing as many as 2 phialides (Fig. 1, E, f, g). In the ascending portions of conidiophorous hyphae, on the other hand, virtually all segments are fertile, with many of them bearing 2 or 3 phialides.

For the most part the phialides are of the familiar flask-shape type that

taper off distally into a single sterigma (Fig. 1, C, a, b; E, a–g). However, instances in which they support plural sterigmata are not altogether infrequent (Fig. 1, A, u–z; D, w–z; G; H, a–c). In such instances 2 (Fig. 1, D, w), 3 (Fig. 1, D, z), or 4 (Fig. 1, G) sterigmata often project separately from the same cell, and must have been put forth independently of one another; but often, again, a rachiform arrangement of sterigmatic tips gives evidence that an apical sterigma, after abstricting some conidia, grew out below its apex to form a second sporogenous tip (Fig. 1, D, x, y), which in turn gave rise to a third (Fig. 1, H, a) and possibly, on repetition of the process, to a fourth and a fifth sporogenous tip (Fig. 1, A, v). Frequently where plural sterigmata of separate origin are present, some may remain simple while one or more of the others undergo successive Beauveria-like prolongation (Fig. 1, A, u, w, x; G; H, b); so that in the end the phialide may offer a rather promiscuously appendaged aspect suggestive of the phialides figured by Petch (7) for his *Cladobotryum ovalisporum*.

It may be presumed that phialides with multiple sterigmata are generally somewhat more prolific than those of unitary make-up. The latter, as a rule, abstrict 5 to 15 conidia, which remain attached in a cohering cluster (Fig. 1, I). Clusters formed aloft in the air disintegrate when the structures supporting them finally collapse; the spores then are left strewn about on the substratum, ready to adhere apically to any specimen of the host nematode that may visit the seeded area. They recall rather strongly the conidia of *Cephalosporium balanoides*, being similarly flattened at the broad distal end and rounded at the narrower proximal end, but owing to their greater length, they show in longitudinal profile (Fig. 1, J, K) less resemblance to an acorn than to a maize (*Zea mays* L.) kernel. A term compounded in part of the generic name of maize is accordingly adopted as an appropriate epithet for the fungus. In view of its frequently liberal production of ascending conidiophorous hyphae, the species is assigned to *Acrostalagmus*, though its varied expression of reproductive habit might be more fully taken into account by resorting to the double citation "*Cephalosporium* (*Acrostalagmus*)" preferred by Petch (6) in naming related entomogenous forms.

Acrostalagmus **zeosporus** sp. nov.

Mycelium nutritum incoloratum, ramosum, septatum, intra vermiculos nematoideos viventes evolutum, in hyphis 2–3 μ crassis constans. Hyphae fertiles extra animal emortuum evolutae, subinde in materia animal ambiente omnino immersae sed saepius magna parte repentes vel ascendentes, hyalinae, vulgo simplices sed subinde ramosae, 10–300 μ longae, plerumque 1.8–3 μ crassae, in cellulis plerumque 5–25 μ longis constantes, plerisque cellulis 1–3 ramulos conidiferos sursum ferentes; ramulis conidiferis (phialis) vulgo lageniformibus, 5–20 μ longis, 2.5–4 μ crassis, plerumque sursum in unico sterigmate 0.6–0.8 μ crasso abeuntibus et 5–15 conidia gignentibus, quandoque tamen 2–4 sterigmates ex ventre proferentibus; sterigmatibus quandoque prope apicem deinceps repullulantibus ad modum *Beauveriae;* conidiis primo cohaerentibus, continuis, incoloratis, inversum elongato-nuciformibus, apice aliquid complanatis, deorsum attenuatis, basi rotundatis, plerumque 3.5–4.6 μ longis, 1.7–2.1 μ crassis.

Panagrolaimum subelongatum necans habitat in foliis caulibusque *Digitariae sanguinalis* putrescentibus in Arlington, Virginia.

Assimilative mycelium colorless, branched at moderate intervals, septate, growing within living nematodes, composed of filamentous hyphae 2 to 3 μ wide. Conidiophorous

hyphae developed outside of dead animal host, sometimes immersed entirely in the surrounding material, but more often largely prostrate or ascending, colorless, commonly unbranched but occasionally branched, 10 to 300 μ long, often 1.8 to 3 μ wide, consisting of cells mostly 5 to 25 μ long, the terminal one, often 25 μ long and as little as 1.5 μ wide, abstricting conidia at its narrow apex, the others mostly bearing 1 to 3 conidiiferous branches (phialides) at the forward end; conidiiferous branches (phialides) commonly flask-shaped, 5 to 20 μ long, 2.5 to 4 μ wide, mostly abstricting 5 to 15 conidia from a single terminal sterigma, but occasionally putting forth 2 to 4 separate sterigmata; the sterigmata whether present singly or plurally sometimes through successive subapical elongation forming one or more additional sporogenous tips in zigzag arrangement; conidia first cohering in a cluster, continuous, coloriess, inversely elongate-nuciform, somewhat flattened at the distal end, narrowing downward, rounded at the proximal end, mostly 3.5 to 4.6 μ long and 1.7 to 2.1 μ wide.

Parasitizing *Panagrolaimus subelongatus* it occurs in decaying leaves and stems of *Digitaria sanguinalis* in Arlington, Virginia.

In connection with the morphological tendencies evident in the new species it may be appropriate to mention here that more than half a century ago a mold very similar to *Botrytis* (now *Beauveria*) *bassiana* was briefly noted by Zopf (8, p. 340) among several fungi he had observed causing nematode diseases.

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THE EFFECTS OF SOIL MOISTURE AND TEMPERATURE ON FUSARIUM WILT OF TOMATO

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During a ten-year study of the Fusarium wilt disease of tomato in connection with a breeding program for the production of wilt-resistant varieties, and the testing of wilt resistance in various commercial varieties, the author observed that John Baer, a susceptible variety, and Marglobe, a resistant variety, seemed to differ in their responses to climatological conditions as related to susceptibility to this disease.

PRELIMINARY RESULTS

The method employed in these wilt-resistance tests has been described in detail elsewhere (13). John Baer and Marglobe were tested in the wilt-infested field each season for comparison with the selections. The same seed stock of these commercial varieties was used each year. When the wilt records of these two varieties for the ten-year period were compared with seasonal temperature and rainfall records of the U. S. Weather Bureau, a very definite relationship between incidence of wilt and soil moisture was indicated that could hardly be coincidental. The graph in figure 1 shows the comparison between the weather data and the wilt records obtained in the field tests.

With the exception of 1933, there was more wilt infection in John Baer in seasons of greater rainfall and less wilt infection when there was less rainfall. However, just the reverse effect seems to occur with Marglobe, *i.e.*, there was a greater incidence of wilt in seasons of less rainfall and less wilt in seasons of greater rainfall. There appeared to be no particular correlation between air temperature and wilt.

REVIEW OF LITERATURE

This preliminary observation is not wholly in accord with that of Humbert (7) and others who state that Fusarium wilt of tomato is favored by dry, hot weather. In an effort to determine whether or not the apparently opposite responses in wilt susceptibility of these two varieties to rainfall as indicated in figure 1 were actual, some tests at constant soil temperature and moisture levels were undertaken.

The relationships between soil temperature and tomato wilt and between temperature and the growth of the causal organism have been well investigated, but little attention has been devoted to a study of the soil moisture relations of this disease. As early as 1920, Edgerton and Moreland (3) determined the optimum temperature for the growth of this fungus. In

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1927, White (18) reported the optimum growth temperature of many different isolants to range from 24° to 28° C., and in 1928, Haymaker (6) stated that a soil temperature of 28° C. was optimum for both the growth of the fungus and the development of the disease. Clayton (1) found that the optimum soil temperature for the development of wilt was 28° C. and the optimum air temperature was from 27° to 35° C.

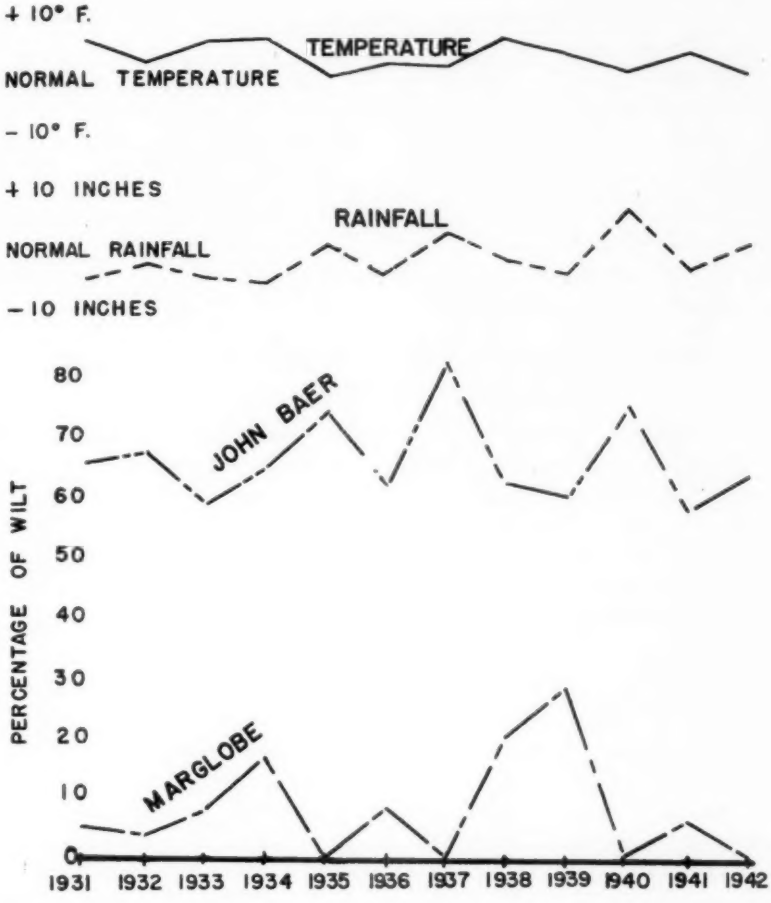

FIG. 1. Graphs showing yearly incidence of Fusarium wilt in two varieties of tomato compared with temperature and rainfall curves for the corresponding seasons.

Clayton (2) also investigated the relation of soil moisture to Fusarium wilt of tomato and reported that plants growing in low-moisture soils were resistant. Plants growing in soil of low moisture content lost their disease resistance if a rapid vegetative growth was induced by the addition of moisture to the soil. Rapidly growing plants which were susceptible were made resistant by allowing the soil to dry out.

Others have studied the effects of soil temperature and moisture on closely related diseases of other crops. Jones and Tisdale (10) stated that

the optimum soil temperature for the development of flax wilt was the same as the optimum temperature for growth of the fungus. Walker (17) reported on the relation of soil temperature to watermelon wilt. Tisdale (16) found that a susceptible variety of cabbage was more susceptible to yellows at a low moisture level than at a higher moisture level. Tims (15) tested both susceptible and resistant varieties of cabbage and found the percentage of infection of both increased with increasing soil temperatures from 20° to 32° C. Only one soil moisture experiment was conducted and "the results were too variable to be of much value."

Elliot (4) stated that cotton wilt was more severe in wet seasons, while Neal (11) held that it was more serious in dry, hot seasons. Neal (12) and Young (19) agreed that the soil temperature most favorable to the growth of the causal fungus was also most favorable for the development of cotton wilt. Tharp and Young (14) found that a susceptible variety of cotton showed positive correlation of disease with a rise in moisture level from 20 to 90 per cent of saturation, while a resistant variety showed little correlation between disease and moisture level.

TESTS WITH CONTROLLED SOIL TEMPERATURE AND MOISTURE CONDITIONS

The constant soil temperature tanks employed in the tests reported here were of the Wisconsin type described by Jones (7, 8) with a heater and thermostat in each tank. As previous investigators had found 28° C. the optimum for the development of Fusarium wilt, this temperature and a lower one, 22° C., were selected for these tests. Two moisture levels, 60 and 85 per cent of saturation of the soil, were also tested. The varieties used were Marglobe and John Baer from the same seed stocks as were employed in the field tests.

In the first tests in 1939 the seeds were planted in sterile soil and the three-weeks-old seedlings were transplanted into the cans. A loam, previously sterilized, was used in the cans, and its moisture content was adjusted to the desired levels. Oat cultures of the causal fungus were added to the soil to furnish inoculum. After the plants were set, a 1-inch layer of ground cork was added on top of the soil to retard radiation and evaporation. The cans were weighed daily and moisture levels maintained by adding distilled water daily or as necessary.

Five plants were in each can, and twenty plants in each test. Five non-inoculated plants of each variety were grown at all soil moisture and temperature levels for comparison as to size.

An air temperature of approximately 22° C. was satisfactorily controlled by thermostat except on bright days when regulation of the ventilators was necessary.

In the first series of tests, in 1939, the development of wilt was observed for 10 weeks. When the final readings were made, the plants were pulled and the basal portions of the stems were cut across and lengthwise so that

browning of the vascular bundles might be observed. This examination was used to verify external symptoms. The final record included dead plants as well as those in various stages of disease. The results of these tests are presented in table 1.

The susceptible variety, John Baer, was more susceptible to wilt at the higher moisture level while the resistant variety, Marglobe, was more susceptible at the lower moisture level. As to the effect of soil temperature, these data show that (with one exception) there was a greater incidence of wilt in both varieties at the higher temperature. A comparison of the noninoculated control plants showed that both varieties produced larger plants at the higher soil moisture and temperature levels. None of the noninoculated plants developed the disease.

TABLE 1.—*The effect of two constant soil moisture and temperature levels upon the development of Fusarium wilt in a resistant and a susceptible variety of tomato. (Twenty plants in each test)*

Variety	Soil moisture content, per cent	Soil temp.	Percentage of inoculated plants infected[a]
Marglobe (resistant)	85	22° C.	20
	85	28	30
	60	22	40
	60	28	40
John Baer (susceptible)	85	22	60
	85	28	90
	60	22	50
	60	28	70

[a] None of the noninoculated control plants developed wilt.

In the winter of 1939–40, these tests were repeated with some innovations. The same numbers of plants were grown in infested soil at each moisture and temperature level for the first three weeks of the experiment, and then half of them were allowed to continue for the remainder of the period with conditions unchanged while the other half were subjected to changes in soil temperature or moisture for the remaining three weeks of the experiment. Twice as many noninoculated control plants were grown as in the previous series and half of these were subjected to the same changes as the inoculated plants.

On Jan. 11, 1940, the basal portions of the stems were examined for discoloration of the vascular system. The percentages of diseased plants occurring under the various sets of conditions were recorded, and are summarized in table 2.

None of the noninoculated plants developed wilt. Changes in soil moisture and temperature levels during the experiment made but slight differences in the final size of the noninoculated plants. Plants of both varieties were larger at the higher soil moisture and temperature levels.

The results obtained in the previous tests were corroborated. Marglobe had more wilt infection at the lower moisture level, while more wilt developed

TABLE 2.—*The effects of constant and changing soil moisture and temperature levels on the development of Fusarium wilt in a resistant and a susceptible variety of tomato during a six-weeks period. Temperature and moisture changes were made at the end of the first three weeks. (Ten plants in each test)*

Variety	Soil moisture content, per cent	Soil temp.	Percentage of inoculated plants infected[a]				
			Conditions constant	Moisture constant		Temp. constant	
				Temp. changes		Moisture changes	
Marglobe (resistant)	85	22° C.	20	.....		85 → 60	40
	85	28	20	28° → 22°	20	.....	
	60	22	30	22° → 28°	40	.....	
	60	28	50	.....		60 → 85	40
John Baer (susceptible)	85	22	80	.....		85 → 60	60
	85	28	90	28° → 22°	90	.....	
	60	22	60	22° → 28°	80	.....	
	60	28	70	.....		60 → 85	90

[a] None of the noninoculated control plants developed wilt.

in John Baer at the higher moisture level. At a constant soil temperature, an increase in soil moisture from 60 to 85 per cent of saturation, decreased the percentage of wilt in Marglobe and increased it in John Baer: the opposite change from 85 to 60 per cent saturation increased the percentage of wilt in Marglobe and decreased the percentage of wilt in John Baer.

In the winter of 1941–42, these tests were repeated using the same seed stock and method except that the inoculation was accomplished by dipping the roots of the seedlings in a suspension of the fungus, as described by Harrison (4), at the time of transplanting into the cans. The noninoculated controls were dipped in sterile water. In this series, a larger number of inoculated plants was used, so that all the possible changes in soil tempera-

TABLE 3.—*A comparison of the effects of constant and changing soil moisture and temperature levels on the development of Fusarium wilt in a resistant and susceptible variety of tomato during a six-weeks period (Dec. 3, 1941, to Jan. 12, 1942). Temperature and moisture changes were made at the end of the first three weeks. (Ten plants in each test)*

Variety	Soil moisture content, per cent	Soil temp.	Percentage of inoculated plants infected[a]				
			Conditions constant	Moisture constant		Temp. constant	
				Temp. changes		Moisture changes	
Marglobe (resistant)	85	22° C.	20	22° → 28°	40	85 → 60	40
	85	28	40	28 → 22	40	85 → 60	60
	60	22	40	22 → 28	50	60 → 85	30
	60	28	60	28 → 22	60	60 → 85	40
John Baer (susceptible)	85	22	90	22 → 28	100	85 → 60	80
	85	28	100	28 → 22	100	85 → 60	90
	60	22	70	22 → 28	80	60 → 85	100
	60	28	80	28 → 22	80	60 → 85	100

[a] None of the noninoculated control plants developed wilt.

ture and moisture could be made and the effects on wilt compared with inoculated plants grown at constant soil moisture and temperature levels.

The tests were set up in the tanks on Dec. 3, 1941, the changes in growing conditions made Dec. 24, and the percentages of wilt were recorded Jan. 12, 1942, when the basal portions of the stems were examined for discoloration of the vascular system. The results of this series of tests are given in table 3.

These data are in accord with those obtained in the two previous tests. Under constant conditions, more wilt developed in Marglobe at the lower moisture level than at the higher level, while more wilt developed in John

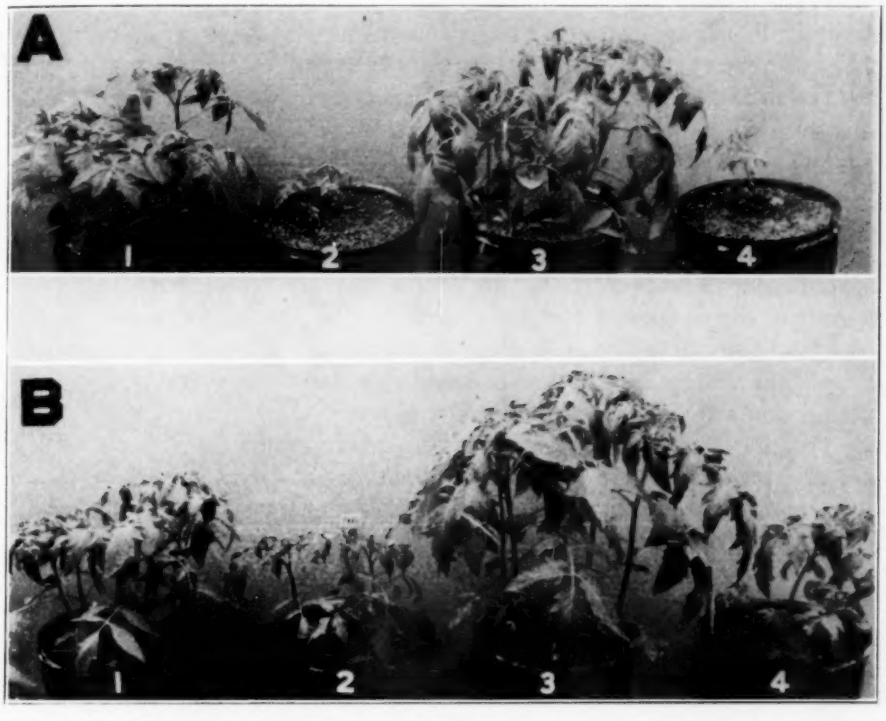

FIG. 2. John Baer (A) and Marglobe (B) tomato plants grown at 28° C. Noninoculated control (1) and inoculated plants (2) at 60 per cent moisture; noninoculated control (3) and inoculated plants (4) at 85 per cent moisture.

Baer at the higher moisture level than at the lower one. In both varieties, the incidence of wilt was greater at the higher soil temperature level. Under changing conditions, at both temperature levels an increase in soil moisture decreased the percentage of wilt in Marglobe, while a decrease in soil moisture increased the percentage of wilt. In the case of John Baer just the reverse was true. At constant moisture levels, the incidence of wilt increased in both varieties with a rise in temperature from 22° to 28° C. while a decrease in temperature from 28° to 22° C. showed no effect on the incidence of this disease.

Photographs of some of the plants of the final experiments are in figure 2.

These pictures compare noninoculated control plants with inoculated plants grown at the same soil moisture and temperature levels. The noninoculated plants of both varieties made better growth at the higher moisture and temperature levels.

DISCUSSION

The results of the three series of tests under controlled conditions of soil moisture and temperature substantiate the apparent relationship between wilt incidence and rainfall shown in figure 1.

These findings corroborate the general observation that hot weather favors wilt, but indicates that dry weather does not favor wilt in all cases. The difference between varieties in response to soil moisture may account for the variation in reports as to the effects of wet and dry seasons on this disease.

The results reported here with John Baer are in accord with those of Clayton (1, 2) who used Chalk's Early Jewel in his investigations. Chalk's Early Jewel is closely related to John Baer and is susceptible to wilt.

The findings with a susceptible variety of tomato recorded here are in agreement with those of Tharp and Young (13) who found that a susceptible variety of cotton showed a positive correlation of disease with a rise in moisture level from 20 to 80 and 90 per cent saturation. These investigators used a resistant variety in only one test and reported little correlation between disease and soil moisture level.

The effects of soil temperature on the development of wilt reported here are in accord with those of other investigators (1, 6, 10, 14, 15, 16, 18).

Whether the difference in effect of soil moisture on wilt incidence is correlated with susceptibility or resistance to the disease, or is merely a varietal difference has not been established in these trials as only one susceptible and one resistant variety were tested under controlled conditions. Since field observations on other varieties were sometimes based on only two trials which were often not in subsequent years, no definite conclusions as to moisture relations can be made. Pritchard, a resistant variety which was tested in the infested field for four years, showed the same response in wilt incidence to rainfall as Marglobe, while the wilt resistant strain of John Baer (13) responded in the same manner as commercial John Baer.

SUMMARY AND CONCLUSIONS

Field observations on the relation of rainfall to the incidence of Fusarium wilt and greenhouse tests at constant soil moisture and temperature levels indicate that Marglobe, a resistant variety, and John Baer, a susceptible variety of tomato, have opposite responses to soil moisture insofar as it affects susceptibility to wilt.

Marglobe was more susceptible to wilt at a soil moisture level of 60 per cent saturation than at 85 per cent, while John Baer was more susceptible to wilt at a soil moisture level of 85 per cent saturation than at 60 per cent.

When soil temperature conditions were constant and soil moisture conditions were changed during the tests, a reduction in soil moisture decreased the incidence of wilt in John Baer, while an increase in soil moisture increased the incidence of wilt. Conversely, in Marglobe an increase in soil moisture from 60 to 85 per cent saturation reduced the incidence of wilt, while a reduction in moisture increased the incidence of wilt.

The responses in wilt susceptibility of John Baer and Marglobe to soil temperatures are similar. Both varieties were more susceptible to wilt at 28° C. than at 22° C. When soil moisture conditions were constant and soil temperatures were changed during the tests, a rise from 22° to 28° C. usually increased the incidence of wilt in both varieties, but a reduction in soil temperature from 28° to 22° C. had no effect on the percentage of wilt which developed.

Whether the difference in effect of soil moisture on wilt incidence is correlated with susceptibility or resistance to the disease, or is merely a varietal difference has not been established in these trials as only one susceptible and one resistant variety were tested.

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INHERITANCE OF REACTION TO CROWN RUST AND STEM RUST AND OTHER CHARACTERS IN CROSSES BETWEEN BOND, AVENA BYZANTINA, AND VARIETIES OF A. SATIVA[1]

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INTRODUCTION

Plant diseases are important limiting factors in the production of oats. Crown rust caused by the pathogen *Puccinia coronata avenae* Erikss. and stem rust caused by *P. graminis avenae* Erikss. and Henn. are two of the more destructive diseases of oats. The modes of inheritance of crown-rust and stem-rust reaction and of several kernel characters are reported herein for crosses between Bond, *Avena byzantina* C. Koch, and several varieties of *A. sativa* L.

The literature concerning the inheritance of crown-rust and stem-rust reaction in oats has been reviewed by Smith (5) and Torrie (7). Hayes, Moore, and Stakman (1) studied crown-rust reaction in crosses involving Bond and 5 different varieties of *Avena sativa*. In 1 of the 5 crosses they found a single factor difference, while in the other 4, two incompletely dominant complementary factors for resistance were carried by Bond. Torrie (7) explained crown-rust reaction in the cross of Iowa No. 444 × Bond on the basis of one factor pair for resistance carried by Bond and an inhibitor carried by Iowa No. 444 which partly inhibited the expression of the factor for resistance. Previous studies (5, 7) have shown that resistance to stem rust is dominant to susceptibility and dependent upon a single factor pair.

The literature up to 1939 on the inheritance of kernel characters has been reviewed by Torrie (7). Hayes, Moore, and Stakman (1) found that the *Avena sativa* type of basal articulation was dominant over the *A. byzantina* type, the ratio approaching 3 : 1. They reported that segregation for floret disjunction (termed rachilla attachment in this paper) in 1 of the 5 crosses studied was monogenic, while in the other 4 crosses it was dependent upon more than a single factor pair for differentiation. In a cross of Iowa No. 444 × Bond, Torrie (7) reported that the characters basal hair length and

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number and basal articulation and rachilla attachment were monogenic in their inheritance, while lemma color and awnedness were digenic.

The literature on the inheritance of earliness of heading has been reviewed recently by Torrie (7). He reports that other workers found a partial dominance of earliness and that one to multiple factors, depending upon the cross, are suggested to explain the segregation.

MATERIALS AND METHODS

The progenies used in these studies consisted of the following:

F_2, F_3, and F_4 of Bond (C.I.[3] 2733) × Hawkeye (C.I. 2464)
F_2 and F_3 of Bond × S.D. 334 (C.I. 2884)
F_2 and F_3 of Hawkeye × Bond
F_2 and F_3 of S.D. 334 × Bond
F_2 and F_3 of Hancock (C.I. 3346) × B. d
F_2 and F_3 of C.I. 3350 × Bond

These varieties belong to the species *Avena sativa*, with the exception of Bond, which belongs to *A. byzantina*. The origins of the parental varieties, with the exception of S.D. 334 and C.I. 3350 have been reported by Stanton (6). S.D. 334 is a selection made at the South Dakota Agricultural Experiment Station from a selection of Swedish Select × Kilby Hulless backcrossed twice to Richland (C.I. 787) and then to Markton (C.I. 2053). C.I. 3350 is a sister selection of Hancock and Marion.

The F_2 and F_3 generations of Bond × Hawkeye were grown successively in 1938 and 1939. The F_2 generation of Bond × S.D. 334 was grown in 1937 and the F_3 generation both in 1938 and 1939, and the F_2 of the remaining crosses in 1939 at the University Hill Farms, Madison. The F_3 lines were planted in 5-foot rows with approximately 25 seeds per row. Parental varieties were seeded at intervals of 30 rows. Border rows of State Pride (C.I. 1154) were planted throughout the nursery to provide a susceptible host for the increase of crown and stem rusts. During 1937 and 1938 naturally occurring inoculum was relied upon for rust infection. In 1939 the natural inoculum was supplemented by inoculating growing plants of State Pride by means of a hypodermic needle.

The seedling reactions to a composite collection of crown rust were determined in the greenhouse. The F_3 generations of Bond × Hawkeye and Bond × S.D. 334 were grown during the winter of 1938–39 while the F_4 of Bond × Hawkeye and the F_2 and F_3 progenies of the other cross were studied during the winter of 1939–40. The crown-rust reactions of 94 F_3 lines of Bond × Hawkeye, selected at random, were determined for physiologic races 3 and 6 and for the composite inoculum during the winter of 1939–40. The seedlings were grown in flats. The first leaf of the seedling plant was inoculated with crown rust. The flats containing the inoculated plants were placed in a lighted moist-chamber for 24 hours at 20° C., after which they were removed to a greenhouse kept at approximately 18° C.

[3] C.I. refers to accession number of the Division of Cereal Crops and Diseases.

All plants, both in the adult plant and seedling stages, were classified for crown-rust reaction into 5 classes: 0, 1, 2, 3, and 4 based on the infection types described by Murphy (4). A large majority of the plants was placed in classes 0, 1, and 4. In the genetic analysis of the data, classes 0, 1, and 2 were grouped as resistant and 3 and 4 as susceptible. All plants were classified for stem-rust reaction as either resistant or susceptible.

The classification for grain characteristics was made in the laboratory by examination of 3 to 4 caryopses of each plant by 2 persons. Three classes were used for all characters: byzantina, sativa, or intermediate type.

The dates when the first, approximately 50 per cent, and the last plant headed were determined for each F_3 and parental line of the crosses Bond × Hawkeye and Bond × S.D. 334. The arithmetic mean of the above three values was taken as an index of the number of days from emergence to heading.

EXPERIMENTAL RESULTS

Inheritance of Crown-Rust Reaction

F_1 plants of all crosses studied had a 1 to 2 crown-rust infection type in the seedling stage under greenhouse conditions and a 3 type in the adult plant stage in the field where the composite inoculum was used.

Data on the F_2 segregation are given in table 1. Good fits were obtained to the ratio of 9 resistant : 7 susceptible in the seedling stage and 5 resis-

TABLE 1.—*Crown-rust reactions of the F_2 progenies of Bond (Avena byzantina) crossed with several varieties of A. sativa, and tests of goodness of fit to the 5 resistant : 11 susceptible and 9 resistant : 7 susceptible ratios in the adult and seedling stages, respectively*

Cross and population	Stage of development	Reaction classes		χ^2 values[a]
		Resistant	Susceptible	
		No. of plants	*No. of plants*	
Bond × Hawkeye	Adult	82	171	0.10
Hawkeye × Bond	Adult	34	94	1.10
	Seedling	164	156	3.05
Bond × S.D. 334	Adult	16	176	1.08[b]
S.D. 334 × Bond (2974)	Adult	41	74	0.82
	Seedling	104	121	8.79
S.D. 334 × Bond (2975)	Adult	25	90	4.46
	Seedling	139	131	4.39
S.D. 334 × Bond (2976)	Adult	44	95	0.00
	Seedling	163	135	0.23
Hancock × Bond (2988)	Adult	31	74	0.07
	Seedling	97	71	0.10
Hancock × Bond (2989)	Adult	36	68	2.96
	Seedling	89	66	0.05
C.I. 3350 × Bond (2983)	Adult	43	71	1.90
	Seedling	112	100	0.87
C.I. 3350 × Bond (2984)	Adult	32	92	1.34
	Seedling	80	64	0.01

[a] The χ^2 values at the 5 per cent and 1 per cent levels for 1 degree of freedom are 3.84 and 6.64, respectively.

[b] χ^2 values for the ratio of 15 susceptible: 1 resistant.

tant : 11 susceptible in the adult plant stage save for the seedling reactions of populations 2974 and 2975 of S.D. 334 × Bond, and the adult plant reaction of population 2975. In the latter 3 instances the proportion of plants classified as susceptible exceeded that expected. The adult plant segregation of Bond × S.D. 334 approached the ratio of 15 susceptible to 1 resistant.

The crown-rust reactions of the F_3 generations of the several crosses and for a selected F_4 of Bond × Hawkeye are given in table 2. The F_4 generation

TABLE 2.—*Crown-rust reactions of F_3 and F_4 progenies of Bond (Avena byzantina) crossed with several varieties of A. sativa, and tests of goodness of fit to the 1 resistant : 4 segregating (3 resistant : 1 susceptible) : 4 segregating (9 resistant : 7 susceptible in the seedling stage and 5 resistant : 11 susceptible in the adult stage) : 7 susceptible ratio*

Generation, cross, and population	Indicated reaction in seedling stage				χ^2 values[b]
	Resistant	Segregating		Susceptible	
		3R : 1S[a]	9R : 7S		
F_3 Bond × Hawkeye	19	73	57	104	3.17
F_4 Bond × Hawkeye[c]	6	58	59	97	4.83
F_3 Hawkeye × Bond	6	24	32	47	1.33
F_3 Bond × S.D. 334	9	12	21	149	1.30[d]
F_3 S.D. 334 × Bond (2974)	10	22	18	60	8.71
F_3 S.D. 334 × Bond (2975)	6	18	27	55	4.38
F_3 S.D. 334 × Bond (2976)	10	27	28	45	1.61
F_3 Hancock × Bond (2988)	12	27	25	40	5.40
F_3 Hancock × Bond (2989)	8	24	24	48	0.79
F_3 C.I. 3350 × Bond (2983)	9	28	30	42	1.73
F_3 C.I. 3350 × Bond (2984)	7	30	30	49	0.14

Generation and cross	Indicated reaction in adult stage				χ^2 values
	Resistant	Segregating		Susceptible	
		3R : 1S	5R : 11S		
F_3 Bond × Hawkeye	23	73	55	102	6.53
F_3 Bond × S.D. 334	11	9	20	151	1.94

[a] R = resistant; S = susceptible.

[b] The χ^2 values at the 5 per cent and 1 per cent levels for 3 degrees of freedom are 7.82 and 11.34, respectively.

[c] Totals for 10 lines, each of which segregated 9R : 7S in the F_3 seedling test.

[d] χ^2 values for the ratio of 1 resistant : 1 segregating (3 resistant : 1 susceptible) : 2 segregating (9 resistant : 7 susceptible) : 12 susceptible.

of Bond × Hawkeye consisted of 10 plants from each of 22 F_3 lines which segregated in a ratio of 9 resistant to 7 susceptible in the F_3 seedling tests. For all crosses, with the exception of Bond × S.D. 334, the segregation was 1 resistant : 4 segregating (3 resistant : 1 susceptible) : 4 segregating (9 resistant : 7 susceptible in the seedling stage and 5 resistant : 11 susceptible in the adult stage) : 7 susceptible. The agreements between the observed and expected ratios were good except for S.D. 334 × Bond (population 2974) where too many F_3 lines were completely susceptible and too few were found in the segregating classes.

The segregation found can be explained by the hypothesis offered by

Hayes, Moore, and Stakman (1) or that by Torrie (7), although the genotype patterns would be quite different. Hayes *et al.* (1) explained the segregation of crosses involving Bond by 2 complementary factors carried by Bond which in the heterozygous condition resulted in somewhat lower resistance than when homozygous. Torrie (7), for the cross Iowa No. 444 × Bond, suggested the presence of two factor pairs, S a factor for crown-rust resistance and I a factor which partly inhibits the expression of S and in which the masking effect of the inhibitor is greater in the adult plant stage in the field than in the seedling stage in the greenhouse. This would explain the difference in the double heterozygous plants which were classified as susceptible in the adult plant stage and resistant in the seedling stage. Since the double heterozygous plants compose one-quarter of the F_2 population the expected segregation in the F_2 and of the double heterozygous plants in the F_3 would be 9 resistant : 7 susceptible in the seedling stage and 5 resistant : 11 susceptible in the adult stage.

The Bond × S.D. 334 progeny segregated somewhat differently than the other crosses. The F_2 segregated into the ratio of 15 susceptible : 1 resistant. The F_3, which was grown in the field in both 1938 and 1939 and in the greenhouse during the winter of 1938–39, segregated approximately as follows: 1 resistant : 1 segregating (3 resistant : 1 susceptible) : 2 segregating (9 resistant : 7 susceptible) : 12 susceptible.

The F_3 reaction of Bond × Hawkeye to races 3 and 6 of *Puccinia coronata avenae* was the same as the reaction to the composite inoculum.

Inheritance of Stem-Rust Reaction

The segregation for stem-rust reaction and tests of goodness of fit for the F_2 and F_3 data are given in tables 3 and 4, respectively. In the adult plant stage F_1 plants of all the crosses studied were resistant. This is in agree-

TABLE 3.—*Stem-rust reaction for the F_2 progenies of Bond (Avena byzantina) crossed with several varieties of A. sativa, and tests of goodness of fit to the 3 resistant : 1 susceptible ratio*

Cross and population	F_2 reaction		χ^2 values[a]
	Resistant	Susceptible	
	No. of plants	*No. of plants*	
Bond × Hawkeye	184	69	0.68
Hawkeye × Bond	98	30	0.17
Bond × S.D. 334	133	58	2.91
S.D. 334 × Bond (2974)	90	25	0.67
S.D. 334 × Bond (2975)	88	21	1.88
S.D. 334 × Bond (2976)	102	37	0.29
Hancock × Bond (2987)	94	11	11.88
Hancock × Bond (2988)	85	19	2.51
Hancock × Bond (2989)	70	23	0.002
C.I. 3350 × Bond (2983)	93	31	0.00
C.I. 3350 × Bond (2984)	96	29	0.23
C.I. 3350 × Bond (2985)	92	37	0.96

[a] The χ^2 values at the 5 per cent and 1 per cent levels for 1 degree of freedom are 3.84 and 6.64, respectively.

TABLE 4.—*Stem-rust reaction for the F_3 progenies of Bond (Avena byzantina) crossed with two varieties of A. sativa, and tests of goodness of fit to the 1 resistant : 2 segregating : 1 susceptible ratio*

Cross	F_3 reaction			χ^2 values[a]
	Resistant	Segregating	Susceptible	
	Number	*Number*	*Number*	
Bond × Hawkeye	59	127	67	0.51
Bond × S.D. 334	49	87	55	1.85

[a] The χ^2 values at the 5 per cent and 1 per cent levels of significance for 2 degrees of freedom are 5.99 and 9.21.

ment with the results reported by Humphrey and Coffman (2) and by Torrie (7). The F_2 data, for the 6 crosses, gave good fits to a 3 resistant : 1 susceptible ratio with the exception of Hancock × Bond (population 2987). The poor fit in the latter case was due to too many plants being classified as resistant. Since the other two populations of Hancock × Bond showed good fits to the 3 : 1 ratio and since the stem-rust epidemic was light in certain portions of the field during 1939, the poor fit obtained for population 2987 is probably the result of certain susceptible plants escaping infection.

The F_3 segregation of the crosses Bond × Hawkeye and Bond × S.D. 334 grown in the field in 1939, gave good fits to the ratio of 1 resistant : 2 segregating (3 resistant : 1 susceptible) : 1 susceptible. These results substantiate the F_2 segregation.

Inheritance of Kernel Characters

The inheritance of several kernel characters, including number and length of basal hairs, type of basal articulation, rachilla attachment, lemma color, awnedness, and twisted black base of awn, were studied for the crosses Bond × Hawkeye and Bond × S.D. 334. Descriptions of the parental varieties, for the characters studied, are given in summary form in table 5.

The F_1 of the two crosses showed partial dominance of the grain characters of the *Avena sativa* parents. The data in table 6 give the modes of inheritance and tests of goodness of fit for the characters studied based on the segregation of the F_3 lines. In the cross Bond × Hawkeye all segregations gave good fits to the 1 : 2 : 1 ratio including that for awn type. Since

TABLE 5.—*Kernel characters of Bond, Hawkeye, and S.D. 334*

Character	Bond C.I. 2733	Hawkeye C.I. 2464	S.D. 334 C.I. 2884
Basal hair length	Medium long	Short	Short
Number of basal hairs	Many	Few to absent	Few
Basal articulation	Sucker	Solid	Solid
Rachilla attachment	Secondary	Primary	Primary
Lemma color	Light reddish brown	Yellow	Yellowish white
Degree of awnedness	Weak awn present	Partly awned	Heavy
Twisted black base of awn	Absent	Absent	Absent

neither parent possessed awns with a twisted black base and since very few plants were found to be as weakly awned as Hawkeye, the exact parentage of the male parent of this cross may be questioned. With this exception, however, all segregations were as expected.

In the cross Bond × S.D. 334 segregation of the F_3 lines for all characters, with the exception of basal articulation, occurred in the ratio of 1 byzantina complex : 8 segregating : 7 sativa complex. Due to various degrees of inter-

TABLE 6.—*F_3 segregation for several kernel characters of Bond × Hawkeye and Bond × S.D. 334, and tests of goodness of fit to the 1 : 2 : 1 ratio for Bond × Hawkeye and to the 1 : 8 : 7 ratio for Bond × S.D. 334*

Class and character	Bond × Hawkeye		Bond × S.D. 334	
	Number of lines	χ^2 values	Number of lines	χ^2 values[a]
Basal hair length:				
Long	58		10	
Segregating	132	0.66	90	0.14
Short	63		79	
Basal hair number:				
Many	60		12	
Segregating	131	0.34	87	0.17
Few	62		80	
Type of basal articulation:				
Sucker	60		12	
Segregating	128	0.23	42	0.49[b]
Solid	65		125	
Rachilla attachment:				
Secondary	63		13	
Segregating	124	0.18	93	0.79
Primary	66		73	
Lemma color:				
Reddish brown	62		12	
Segregating	125	0.17	91	0.15
Yellow to white	66		76	
Awning:				
Weak awned	63		14	
Segregating	122	0.55	87	0.78
Heavy awned	63		78	
Twisted black base of awn:				
Absent	65		13	
Segregating	126	0.07	90	0.37
Present	62		76	

[a] The χ^2 value at the 5 per cent and 1 per cent levels for 2 degrees of freedom are respectively 5.99 and 9.21.

[b] χ^2 value for the 1 : 4 : 11 ratio.

mediacy no attempt was made to differentiate between the segregating lines. The segregation suggests the presence of complementary factors, both present in a dominant homozygous condition in S.D. 334 and carried in a recessive condition in Bond.

The segregation for basal articulation occurred in a ratio of approximately 1 byzantina : 4 segregating : 11 sativa. In the classification of this character both in the F_2 and F_3 the plants of intermediate type of basal articulation approached very closely the articulation type found in the sativa

parent. Since segregation for this character was not clear-cut, many plants which were intermediate were placed in the sativa complex. This would result in some of the segregating F_3 lines being classified as homozygous for the sativa complex. This is probably the reason for the different ratio found in the F_3 for this character as compared to that found for the other characters studied.

The data in table 7 show the linkage intensities between the kernel characters for the cross Bond × Hawkeye, which were calculated from the F_2 and the F_3 data by the method of maximum likelihood described by Immer (3). Genes for all kernel characters studied were located on the same chromosome.

In the cross Bond × S.D. 334, the inheritance of each kernel character was

TABLE 7.—*Linkage intensities between genes for several kernel characters in the cross Bond × Hawkeye*

Character	Linkage intensities with standard error					
	Awnedness	Twisted black base of awn	Basal articulation	Hair number	Rachilla attachment	Basal hair length
Twisted black base of awn	8.7 ± 1.2					
Basal articulation	19.4 ± 1.9	11.7 ± 1.5				
Hair number	26.5 ± 2.3	18.4 ± 1.8	6.9 ± 1.1			
Rachilla attachment	30.8 ± 2.5	24.4 ± 2.2	20.1 ± 2.0	17.7 ± 1.7		
Basal hair length	42.1 ± 2.9	38.9 ± 2.8	32.2 ± 2.6	25.6 ± 2.3	22.3 ± 2.2	
Lemma color	58.7 ± 3.4	50.0 ± 3.0	47.8 ± 3.1	46.4 ± 3.0	44.0 ± 3.0	26.8 ± 2.3

Chromosome map showing linear order of genes[a]

a	tbb	ba	hn	ra	hl	lc
8.7	11.7	6.9	17.7	22.3	26.8	

[a] a = awnedness; tbb = twisted black base; ba = basal articulation; hn = hair number; ra = rachilla attachment; hl = hair length; lc = lemma color.

digenic. Chi-square tests of independence and association showed that the genes governing all the characters were closely linked. The P values in all cases were considerably less than 0.01.

Inheritance of Earliness of Heading

The distribution of the F_3 lines of the crosses Bond × Hawkeye and Bond × S.D. 334 and parental varieties for number of days from emergence to heading are given in figure 1. The distribution of the F_3 lines of Bond × Hawkeye show that approximately one-third of the lines were earlier than Bond, and one-third as early as Bond. Seven of 253 lines studied were as late as Hawkeye, which is approximately one sixty-fourth of the entire population. The segregation found suggests that at least 3 factor pairs are involved and that Hawkeye, the late parent, possesses genes for earliness of heading.

The distribution of the F_3 lines of the cross Bond × S.D. 334 show that approximately one-third were as late as the late parent, S.D. 334, and one-quarter as early as the early parent, Bond. The distribution suggests that at least 1 main factor pair and possibly 1 or more modifying factors are

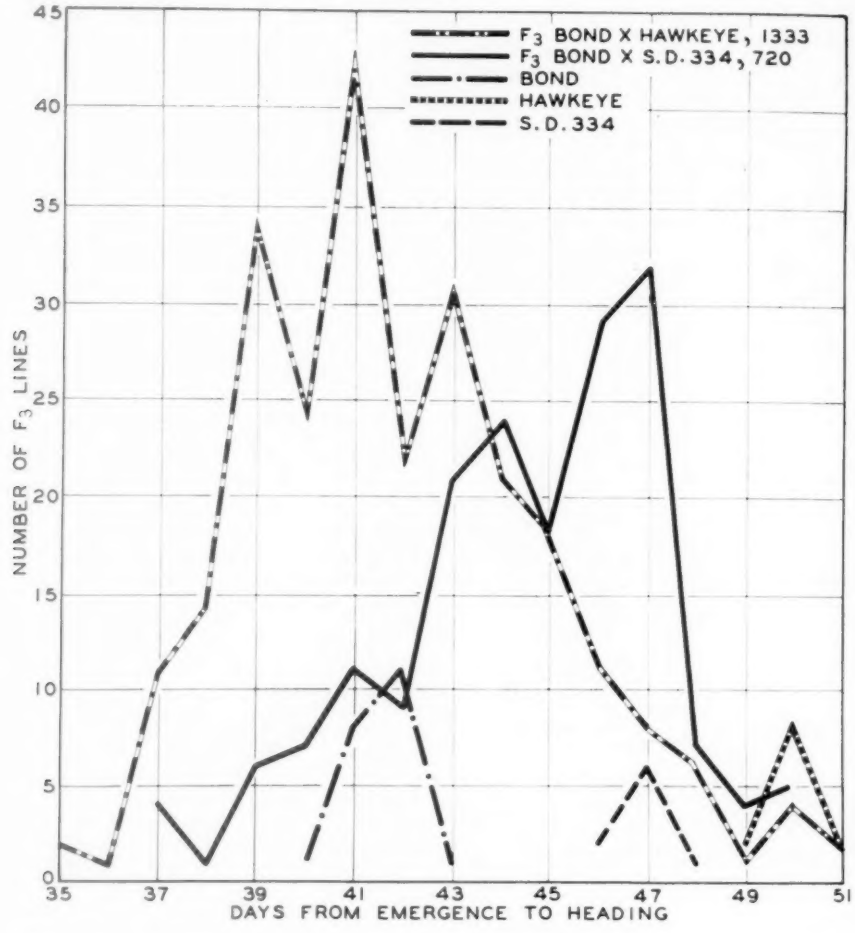

FIG. 1. The distribution of days from emergence to heading of F_3 lines for the crosses Bond × Hawkeye, Bond × S.D. 334 and parental varieties.

involved. A few lines earlier and later than either parent suggest the possibility of transgressive segregation.

SUMMARY

A study was made of the mode of inheritance of reaction to crown rust, *Puccinia coronata avenae*, and stem rust, *P. graminis avenae*, several kernel characters, and earliness between crosses involving several varieties of *Avena sativa* and Bond, *A. byzantina*.

The segregation found for crown-rust reaction in all crosses, save

Bond × S.D. 334, can be explained by either the hypothesis of two complementary factors carried by Bond as suggested by Hayes *et al.* (1), or that of two factor pairs, S a factor for crown-rust resistance and I a factor which partly inhibits the expression of S as suggested by Torrie (7). Plants heterozygous for both factor pairs were more susceptible in the field than in the greenhouse.

A single factor pair with dominance of resistance governed stem-rust reaction.

In the cross Bond × Hawkeye the characters of basal hair length and number, basal articulation, rachilla attachment, lemma color, awnedness and twisted black base of awn were monogenic and linked. In the cross Bond × S.D. 334 the same kernel characters were digenic and linked.

A partial dominance of earliness of heading was found in the cross Bond × Hawkeye, while in the cross Bond × S.D. 334 lateness of heading was dominant over early heading.

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PHYTOPATHOLOGICAL NOTES

Experiments with New Organic Fungicides for Control of Apple Scab and Brooks' Fruit Spot (Phoma pomi).[1]—Cooperative apple-scab-control experiments were conducted in Delaware on the Red Delicious and Rome varieties of apples and in New Jersey on the Rome variety during the 1944 growing season. Several of the newer organic fungicides were tested in dosage series. The test on the Rome trees in the Delaware experiment was begun after scab had become established in the planting.

In the Delaware experiments, U. S. R. No. 604 (2,3-dichloro-1,4-naphthoquinone) at 1 and 1½ pounds per 100 gallons and Puratized N5–X (phenyl mercuri triethanol ammonium lactate) at 1–1,000 (1–8,600 active ingredient) and at 1–2,000 (1–17,200 active ingredient) equalled liquid lime-sulphur at 1½ gallons per 100 gallons of water for scab control. Fermate (ferric dimethyl dithiocarbamate) at 1½ and 2 pounds per 100 gallons, Fermate at ½ pound plus ½ the recommended quantity of Micronized Sulfur, No. 604 at ¾ pound or at ⅜ pound plus $ZnSO_4$-lime ½–½, and Isothan Q–15 (lauryl isoquinolinum bromide) at 1–1,000 (1–5,000 active ingredient) equalled the standard wettable sulphurs in providing protection against scab. He 175 (disodium ethylene bisdithiocarbamate) as used (0.45 to 1.8 pounds per 100 gallons) either alone or in combination with zinc sulphate–lime failed to provide satisfactory control of apple scab.

The scab control in the New Jersey experiments was in the same order as those in Delaware, with the exception that No. 604 at the 1-pound dosage and Isothan Q–15 dropped to slightly below the efficiency of a wettable sulphur.

In an experiment at Cheswold, Delaware, designed to compare the eradicant value of Puratized N5–X with liquid lime-sulphur, Rome trees with scab on the foliage and fruit were either left unsprayed or were sprayed with lime-sulphur or Puratized N5–X. Puratized N5–X, at 1–1,000 and 1–2,000, had eradicative properties at least equal to those of lime-sulphur: only 9.5 and 10.5 per cent of fruit was infected after Puratized treatment, 17 per cent after lime-sulphur spray, and 97 per cent on trees without treatment.

In experiments in New Jersey during the last 3 years on the Stayman variety, Thiosan (tetramethyl thiuram disulphide) at ¾ pound in 100 gallons, Fermate at ¾ pound, and lead dimethyl dithiocarbamate at ¾ pound have given excellent control of Brooks' fruit spot (Table 1), when used at the 17-, 27-, and 37-day (after petal fall) applications. Trees sprayed with these materials, used with or without oil, have been remarkably free from spray injury. In 2 of the 3 years that Fermate has been used during the early cover spray period, lime in combination with this material has not produced any more russetting than has Fermate wtihout lime. In 1943, however, the combination of lime and Fermate was more phytocidal, as judged by fruit russetting, than was Fermate alone. Where No. 604 was used with

[1] Journal Series paper of the New Jersey Agricultural Experiment Station, Rutgers University, Department of Plant Pathology.

TABLE 1.—*Control of Brooks' fruit spot on Stayman apple at Vincentown, New Jersey, in 1942 and 1943*

Pounds of materials used in 100 gallons of water[a]	1942	1943	
	Fruit free from	Fruit free from	
	Fruit spot	Fruit spot	Russett
	Per cent	*Per cent*	*Per cent*
Lead dimethyldithiocarbamate, lime, 2–3	99.0	.....	.....
Tetramethyl thiuram disulphide, lime, 2–3	98.7	.....	.....
Fermate, lime, 2–3	98.7	.....	.....
do , 1½	.....	98.5	97.6
do , ¾	.....	97.5	94.7
do , lime, ¾–3	.....	98.1	84.6
Bordeaux, ½–4	94.9	87.3	90.7
do , ½–4 + Coposil, ½	97.1	96.8	92.1
Lime, 3	75.0	61.6	97.4
Micronized Sulfur, lime, 4½–3	75.8	62.5	92.6
Check, not sprayed	12.9	5.6	94.6

[a] All spray combinations carried 3 lb. of lead arsenate in the 17-day and 2 lb. in the 27- and 37-day applications. A summer oil emulsion was used at the rate of 0.75 per cent in the diluted spray at the 27- and 37-day applications.

oil, excessive injury occurred. Oil was used with Puratized N5–X, Isothan Q–15, and He 175 during 1945 without increasing the injury to apple foliage or fruits. The combination of Puratized N5–X with oil was very toxic, however, to poison ivy growing under the trees. In Delaware, No. 604 and oil produced excessive injury to Rome, whereas injury was slight with Puratized N5–X and oil.—ROBERT H. DAINES, Associate Plant Pathologist, New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, New Jersey, and S. L. HOPPERSTEAD, Associate Research Professor in Plant Pathology, Delaware Agricultural Experiment Station, Newark, Delaware.

Ring-Rot-Like Symptoms Produced by Soft-Rot Bacteria in Potato Tubers.[1]—In 1944, many potato fields in Minnesota were flooded by heavy rains at harvest time, resulting in various types of decay, both in the field and in storage. While the effect of water on tuber decay was being studied in the laboratory, symptoms similar to those of bacterial ring rot (*Corynebacterium sepedonicum*) were observed. (See figure 1, B.) Soft-rot bacteria (*Erwinia carotovora*) appeared to be the cause of the symptoms which had not been seen previously, or at least not recognized, in the field or on stored tubers from flooded fields.

Certified seed stock of the Cobbler variety, which had been stored for approximately seven months under optimum storage conditions, was used in the original experiment. The tubers were submerged in water held at the constant temperatures shown in figure 2, and were removed from the water and examined at the time intervals indicated in the same figure.

[1] Paper No. 2252, the Scientific Journal Series, Minnesota Agricultural Experiment Station.

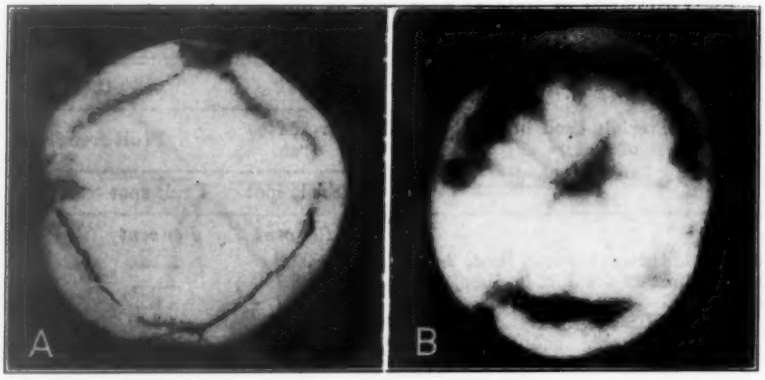

FIG. 1. A. Ring-rot-like symptoms produced by soft-rot bacteria in tuber of Cobbler; B. Bacterial-ring-rot symptoms produced by *Corynebacterium sepedonicum* in the same variety.

Figure 1, A, illustrates the symptoms, which resemble those of ring rot in that the tissue in the region of the vascular ring decays and this causes the cortex to separate easily from the medulla. In the earlier stages of breakdown the infection in the vascular area radiates away from the stem end and from the eyes of the tuber, indicating that infection occurs at these points. When a slight pressure is applied to a cut tuber, a white to cream-color ooze exudes from the infected portion of the vascular elements. This ooze, however, is lighter than that associated with ring rot and is creamy rather than cheesy in consistency. A water-soaked area extends on both sides of the vascular elements as seen in figure 1, A. The relation of temperature and length of time flooded to the occurrence of this type of vascular decay is indicated in figure 2.

The experiment was repeated, using again the Cobbler variety from the same source, certified seed stock of Bliss Triumph which had been stored for the same period of time, and immature Bliss Triumph tubers from Texas which were obtained on a local early spring produce market. The results with tubers of the Cobbler variety were the same as those reported in figure 2. The stored Triumph tubers responded similarly except that they

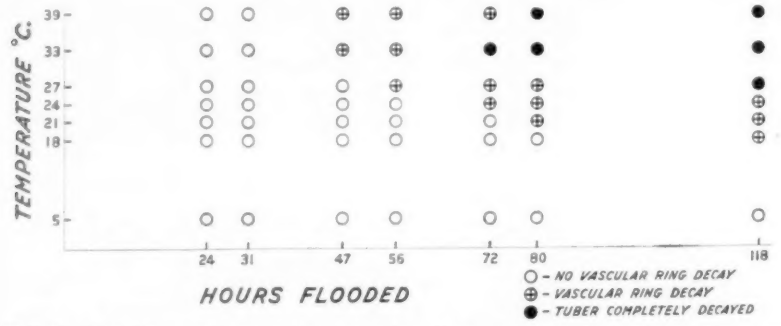

FIG. 2. Relation of temperature and length of time flooded to the occurrence of ring-rot-like symptoms in tubers of Cobbler.

appeared to be slightly more susceptible to infection than the Cobbler. The symptoms appeared in the new Triumph tubers 48 hours after being observed in the stored Triumph tubers.

All isolations from affected tubers have yielded Gram-negative bacteria of the Erwinia soft-rot group. Thus it appears that soft-rot bacteria, in potato tubers which are subjected to the conditions described, may produce symptoms resembling those produced by the bacterial ring-rot organism.—R. S. DAVIDSON, University Farm, St. Paul, Minnesota.

Sclerotium Rot of Potato Seed Pieces.—Sclerotium rolfsii Sacc. was found attacking potato seed pieces in a field near Hastings, Florida, in March, 1945. Cabbage had been grown in this field during the winter and after that crop was removed the field was planted to potatoes of the Sebago

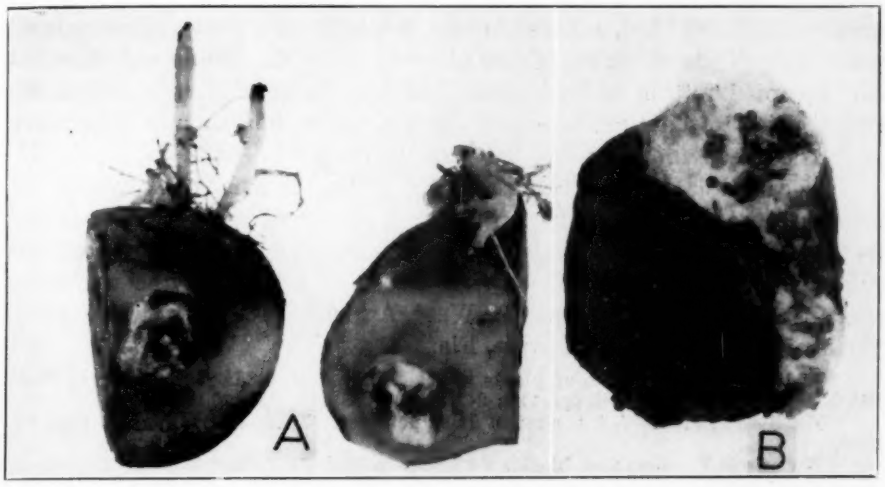

FIG. 1. Mycelium of *Sclerotium rolfsii* growing in seed pieces which had been naturally infected in the field (A), and typical mycelium and sclerotia of *S. rolfsii* on a naturally infected piece held in a moist chamber for 5 days (B).

variety on February 15. The soil was extremely dry when the potatoes were planted and it remained dry until the latter part of March as no rain fell to wet it and the field was not irrigated. The seed germinated poorly. Some pieces failed to produce sprouts or roots while others formed a few roots and clusters of sprouts similar to those seen on sprouted tubers in storage bins. The tips of most sprouts shriveled, died and turned brown in the hot, dry sand as soon as they emerged from the soil and were exposed to the sun. When seed pieces were examined, one month after planting, approximately 4 of each 10 were affected with a rot which originated on the cut sides of the pieces. A white mycelium resembling that produced by *S. rolfsii* was found in decayed holes in the pieces. Mycelium grew very rapidly on decaying pieces placed in a moist chamber (Fig. 1, A), and typical sclerotia of *S. rolfsii* formed on one piece kept in the chamber for 5 days (Fig. 1, B).

Bits of the mycelium of the organism were taken from the rotting pieces and placed in contact with healed and nonhealed cut surfaces of seed pieces which were then planted 2 inches deep in sand in 8 flower pots. Four pots were watered and four received no water. When examined 7 days later, small decayed areas were found in inoculated pieces in dry soil, but the pieces in wet soil had been almost completely destroyed by rot. Characteristic mycelium of *S. rolfsii* was present on pieces removed from wet soil and when one of these was held in a moist chamber for one week, the fungus produced abundant sclerotia. Mycelium and sclerotia also were found in the dirt and on inoculated pieces left in dry soil for 2 weeks. Healed seed pieces became infected as soon as the freshly cut pieces when the organism was placed in contact with the cut surfaces. The flesh of affected pieces was soft and white in decayed areas but no offensive odor was present.

A sclerotium rot of tubers caused by *S. rolfsii* occurs throughout the southern states[1, 2, 3] but, so far as known, this is the first report of the natural occurrence of sclerotium rot of seed pieces in the field. Edson and Shapovalov[4] recorded rotting of seed which had been inoculated with *Sclerotium rolfsii* prior to planting, but they did not report finding any seed pieces which had been naturally infected with the disease in the field.

The causal organism is being reported under the name of the vegetative stage because no basidial stage was found associated with the disease and no very clear-cut characters have been reported for separating *Corticium rolfsii* (Sacc.) Curzi and *C. centrifugum* (Lev.) Bres. in the vegetative stage.—A. H. EDDINS and ERDMAN WEST, Agricultural Experiment Station, University of Florida, Gainesville, Fla.

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